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Transistor Characteristics and Circuits

As expansion continues rapidly in plans for new telecommunications equipment employing transistors, a fundamental working knowledge of these modern circuit components will be required by more and more communications personnel. The carrier telegraph channel terminal and automatic switching systems are definite applications but only two of many in which transistor circuitry will be found.

In the July 1957 issue of TECHNICAL REVIEW an article by Oscar E. Pierson presented simplified explanations of the phenomena of conduction by conductors and semiconductors, of the difference between N-type and P-type semiconductors, why the junction between N-type and P-type semiconductors has rectifying properties and, lastly, how three-connection PNP or NPN transistors may be formed and how the current flow through them takes place.

It is the purpose of this paper to examine the characteristics of transistors which result from the concepts and theories explained by Mr. Pierson, and to present in a simplified and instructional way some of the features of the more common elementary circuits in which they are employed.

Symbols

In order to talk about these devices effectively it will be necessary to use symbols of various kinds. Unfortunately, at the present time, there are a number of different symbols being used by various workers in the field to represent the same things. The ones used here are taken from the Institute of Radio Engineers' Symbol Standard for Semiconductor Devices.

The symbols for PNP and NPN transistors are shown in Figure 1, and are used, of course, without the lettering. As will be noted, the only difference is the direction of the arrow on the *emitter* lead which indicates the "conventional" (plus-to-minus) direction of current flow for low resistance conduction through the diode. The forward direction of the *collector* diode is, of course, the same but the line representing the collector lead is left unmarked to differentiate it from the emitter without the need for the lettering which is not part of the symbol.

Curves will be shown in the first quadrant regardless of the polarites involved.

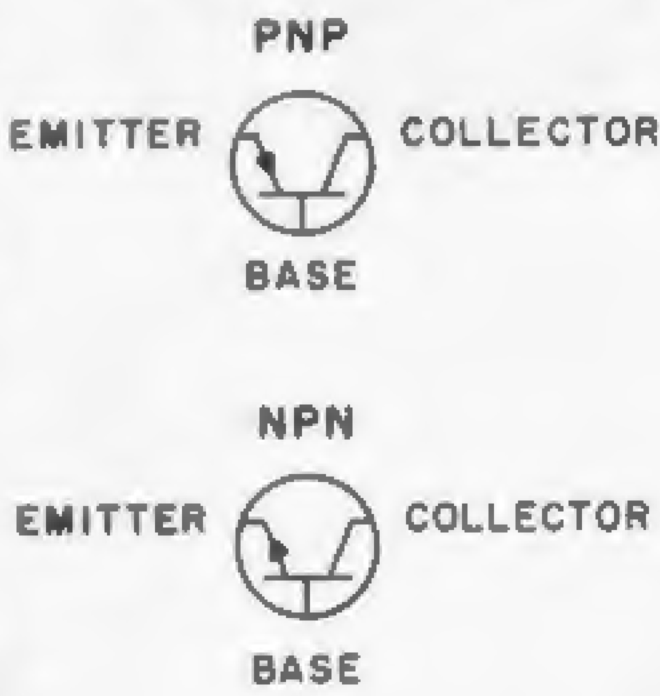


Figure 1.

Where the letter E with a subscript is used, it will mean the potential between the element indicated by the subscript, as *E* for Emitter, and the common element.

All explanations will be made on the basis of PNP junction type germanium transistors. NPN transistors have similar characteristics, so far as the explanations given here go, except that all polarities are reversed. The explanations are valid for silicon transistors too. Silicon transis-

tors have much lower values of collector leakage current which, as will be seen, makes them more suitable for high temperature operation than ones made with germanium.

Diode Characteristics

If a circuit were set up like that shown at A of Figure 2 and data taken and plotted, the usual diode characteristics such as are shown at B and C would result. With everything left as before except the connection shifted from the emitter to the collector, similar data would be obtained. These curves would be slightly different depending upon whether the remaining connection were left open-circuited or short-circuited to the base. Thus it is seen immediately that the impedance connected in either circuit will affect the other circuit. However, to account for this and certain other effects which take place in the various circuits to be described requires more advanced methods of analysis than will be used here.

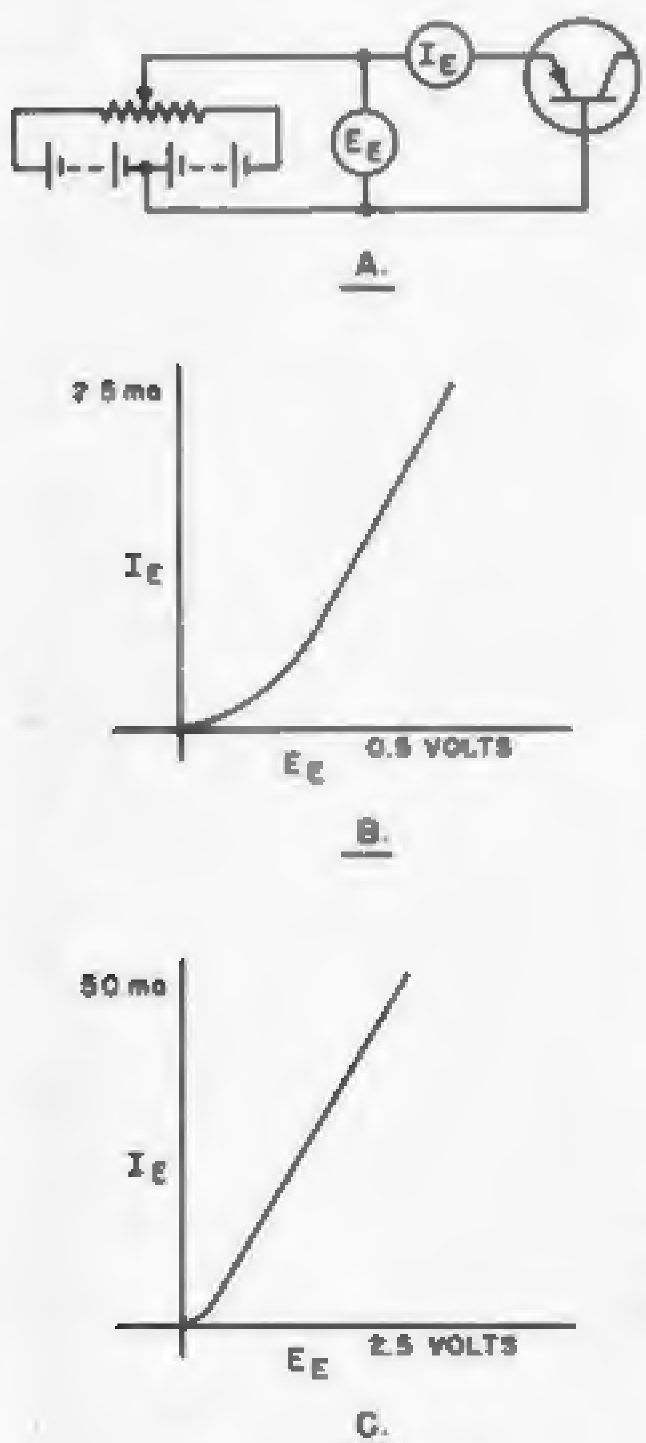


Figure 2.

It should be noted that the curve, Figure 2B, showing the characteristic at low potential and current, has considerable curvature but that Figure 2C, for high potential and current, is quite linear, the highly curved portion now being confined to such a small range as to be almost unnoticeable.

Grounded Base Characteristics

Suppose the circuit is now added to, as shown in Figure 3. This arrangement is called the "common base" circuit because the base connection is common to both the emitter and collector, that is, input and output circuits. When data are taken, it will be found that the relationship between E_E and I_E is only slightly affected by the presence of a negative potential applied to the collector. The current in the collector circuit, on the other hand, is very dependent upon how much current is flowing in the emitter circuit—considerable or full current actually flowing in the collector circuit of some transistors with no potential at all applied in it. Further, as the potential at the collector is made negative relative to the base, which is the reverse or high resistance direction of the collector diode, the current will rise, if necessary, until it approaches closely the value of the current in the emitter circuit. Further increases in E_C result in small increases in I_C such as might be expected through the back resistance of a diode. As the current I_C rose, the value of I_B, which with the collector circuit open was equal

to I_B, would drop, the following relationship holding:

$$I_B = I_E - I_C \text{ or } I_C = I_E - I_B$$

To get a complete picture of the transistor's characteristics in this circuit one can set E_E or I_E to various preselected values and then vary E_C and note the relationship between E_C and I_C which results. The relationship between E_E and I_E has already been determined so only one or the other need be noted. Because it is useful to compare I_E with I_C it has become the usual practice to note I_E although occasionally curves for values of E_E are included.

A typical family of transistor collector characteristics taken in this way on a small transistor is shown by Figure 4. As indicated earlier, the shape and location of the curves near the I_C axis may vary considerably from one manufacturer and catalog number of transistor to another. The shape of the curves farther out in the field, however, is generally correct for all transistors.

The slope of the curves represents the resistance which the collector circuit would present to any variation in E_C, such as would be caused by the presence of a signal if a load were connected in the circuit as shown in Figure 5. This collector resistance is equal to the change in collector potential divided by the change in collector current which it causes. It is called the collector dynamic resistance and is the same anywhere in the field that the slope of the curves is the same, as distinguished from the d-c collector resistance whose value depends entirely upon the particular point chosen. Symbolically,

$$r_c = \frac{\Delta E_C}{\Delta I_C} \qquad \text{(dynamic)}$$

$$r_C = \frac{E_C}{I_C} \qquad \text{(d-c)}$$

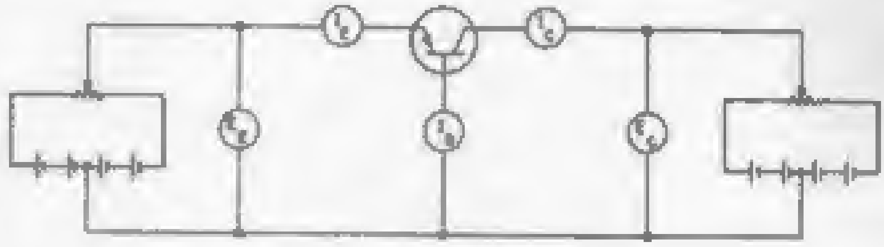


Figure 3.

Restrictions on Use

When a resistance load R_L is added to the collector circuit, E_C will no longer be equal to E_{CC}, the collector supply potential, but will be lower by the potential drop in R_L. When the emitter current is zero the only current in the collector circuit will be the collector leakage current I_{CO}. This current may be very small in a good transistor so under these circumstances E_C is very nearly E_{CC}. For this reason E_{CC} must not be greater than the maximum rated E_C of the transistor. It may be made smaller to conserve battery power if the full power capability of the transistor is not required or if it is desired

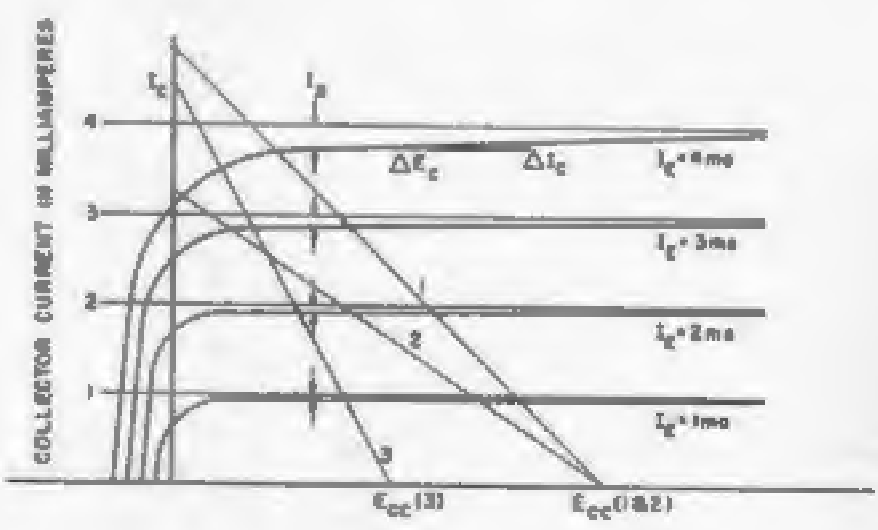


Figure 4.

only to control current in a low resistance load.

Other restrictions on the use of the transistor are its heat dissipation capabilities and the maximum current which the junctions can pass without damage. The heating power in the transistor is very nearly $I_C \times E_{CE}$ in this circuit. The maximum safe limit for this value is given by the manufacturer. Two such limiting curves are shown on Figure 7.

The Load Line

If now I_E is made to increase, as I_C follows suit, E_{RL} will increase and E_{CE} decrease by a like amount. Thus if E_C is plotted against I_C as I_C varies, a straight line will be obtained such as 1, 2 or 3 shown on Figure 4, depending upon the value of R_L and E_{CC} selected. The lower the value of R_L the smaller the potential drop for any value of I_C and consequently the steeper the slope of this plot which is known as the "load line."

The maximum power which can be developed in a load is proportional to the product of the potential and current subtended by its load line. These will be approximately the peak-to-peak values. The actual power will be the product of the root mean square values. These are equal to the individual peak-to-peak values divided by two and multiplied by 0.707. Thus the approximate actual power is the product of the values subtended by the load line divided by eight:

$$\frac{E_{PP}}{2} \times 0.707 \times \frac{I_{PP}}{2} \times 0.707 = \frac{E_{PP} \times I_{PP}}{8}.$$

If a load line is "laid in" to best advantage, taking into consideration all the limitations placed upon the use of the transistor, as is shown on Figure 7, its value may subsequently be worked out by the incremental methods but is most easily found from $R_L = \frac{E_C}{I_C}$ where E_C is the point where it intersects the potential axis and I_C the point where it intersects the current axis. (R_C and R_L have opposite slopes because E_{RL} represents a potential drop from E_{CC}, a fixed potential above reference, while E_C represents a rise in potential from reference potential toward E_{CC}.)

Bias, Gain, Power

If the transistor is set up in a circuit such as shown by the circuit diagram of Figure 5, it is found that the emitter battery provided causes a current to flow which biases the circuit to point P_E in the emitter circuit and point P_C in the collector. Both of these points must be in linear areas of the curves if low distortion amplification is wanted. A signal potential applied in the emitter circuit may then cause variations in both circuits as shown.

At first sight it may seem that this circuit does not result in amplification since the signal current variations in the output circuit are less than those in the input circuit. However, amplification by a transistor circuit must be thought of on a power basis. Examining the situation from this point of view one sees that a peak-to-peak signal of one-quarter volt resulted in a peak-to-peak current variation of two milliamperes in the input circuit. This 2-ma variation in the input circuit showed up in the output circuit as 1.9 ma but caused a peak-to-peak potential variation across the load of 10 volts. Thus the power gain G may be written as

$$G = \frac{\text{output power}}{\text{input power}} = \frac{P_O}{P_{IN}}$$, which is proportional to $\frac{10 \times 1.9}{0.25 \times 2} = 38$ *or a gain of 15.8 db*

The fact that there is a little less power than there would have been had the current in the collector circuit been the same as that in the emitter, points up the importance of the ratio between them. Since it is different for different transistors, it is one of the important constants and may be defined as "a small change in collector current divided by the change in emitter current required to cause it, with the collector potential held constant." It is called the "common-base short-circuit current

transfer ratio." The symbol for it is α_b, the subscript indicating common base.

The transistor used in this example, therefore, must have

$$\alpha_b = \frac{1.9}{2} = 0.95$$

which is toward the lower limit for modern transistors.

When the curves are practically horizontal, as is the case in the common base connection, the current ratio changes very little with the insertion of a load in the collector circuit, providing operation is kept away from the axis. In this case one may say

$P_{IN} = i_{IN}^2 r_{IN}$ and $P_o = (\alpha_b i_{IN})^2 r_o$, whence

$$G = \alpha_b^2 \frac{r_o}{r_{IN}}$$

For most efficient use of the signal power available from the source, its impedance should be matched to the input resistance of the transistor circuit. This may be obtained around the bias point by the incremental method. If one takes the peak-to-peak signal values of Figure 5 as increments, one would get for this case

$$r_{IN} = \frac{\triangle E_{IN}}{\triangle I_{IN}} = \frac{0.25}{0.002} = 125 \text{ ohms}$$

On the output side one sees from the construction on the 4-ma curve of Figure 4 that the emitter resistance of the transistor in this circuit is extremely high. A load line to match it would have equal but opposite slope and lie so close to the zero axis that no appreciable power would be developed in it. If the output resistance of the amplifier must match the impedance of the load it can be made to do so by the proper application of feedback.

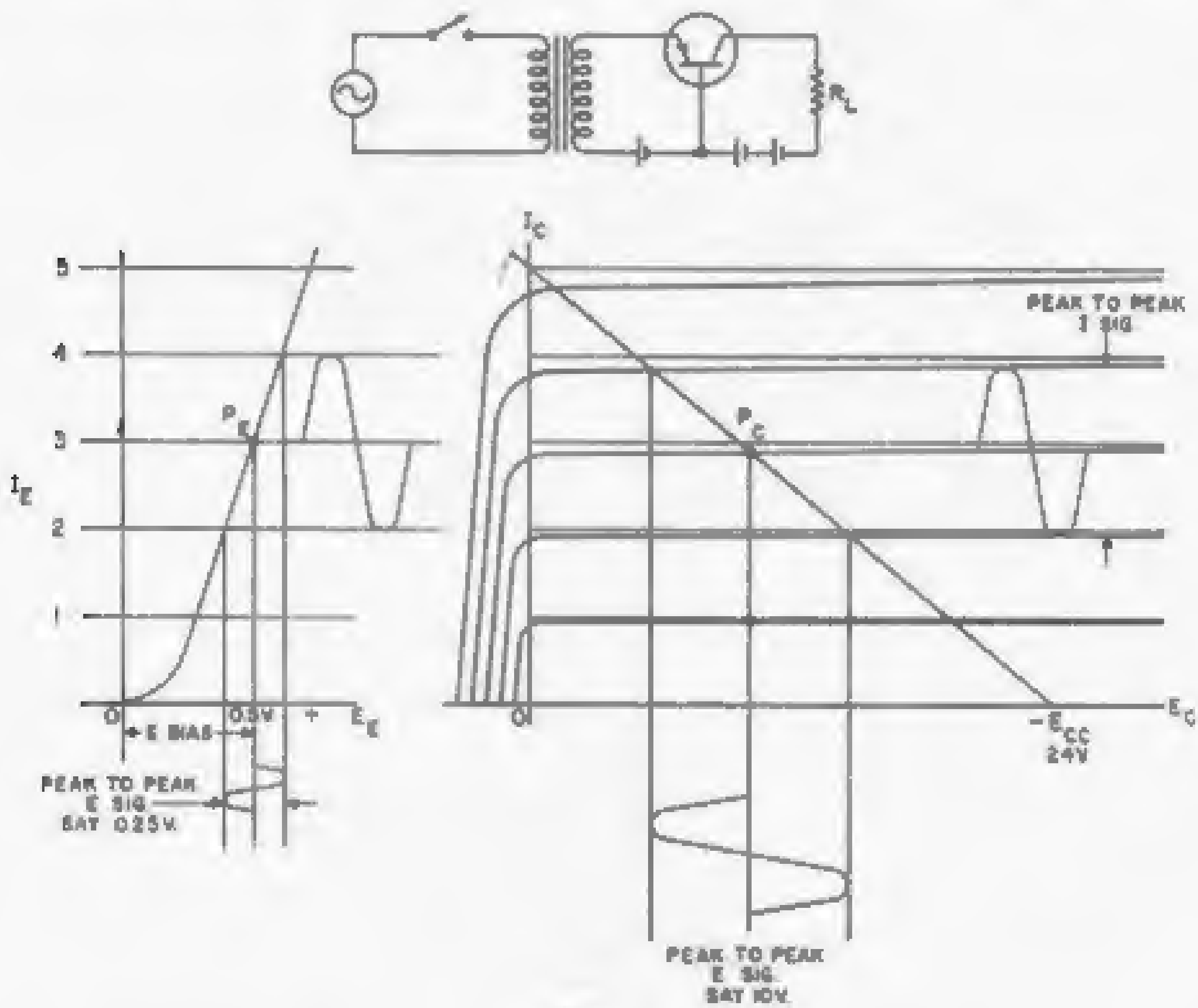


Figure 5.

The Common Emitter Configuration

In addition to the common-base configuration, which has been examined, a

transistor may be connected into a circuit with either its emitter or collector as the common connection. Of the three possible arrangements the common emitter circuit is the most used. In this circuit, an elementary form of which is shown by Figure 6, as in the common-base circuit, the currents in the emitter circuit and the collector circuit, when there is no load resistance present, are related by α_b, the difference between the two flowing in the base circuit. The ratio of the current in the base circuit to that in the emitter tends to remain fixed and is, therefore, as before,

$$I_B = I_E - \alpha_b I_E$$

The common emitter short-circuit current transfer ratio α_e then is

$$\alpha_e = \frac{\Delta I_C}{\Delta I_B} = \frac{\alpha_b \Delta I_E}{\Delta I_E - \alpha_b \Delta I_E} = \frac{\alpha_b}{1 - \alpha_b}$$

(The symbol β is very commonly used in the literature in place of α_e and α in place of α_b)

This turns out to be 19 for a transistor with an α_b of 0.95 and rises rapidly as α_b increases.

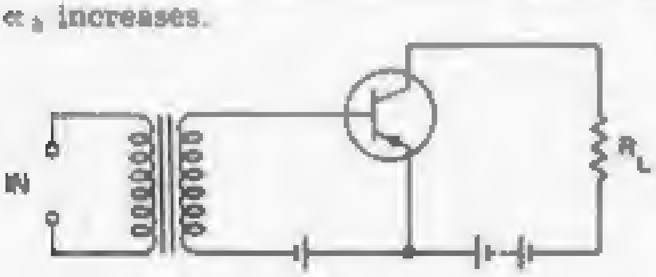


Figure 6.

The collector family for a power transistor connected in the common emitter configuration is shown by Figure 7. Here the useful field is bounded at the top by the maximum collector current which could ordinarily be usefully employed, on the lower right by the maximum safe collector to emitter potential, and between these by two curves of maximum allowable dissipation. These curves apply to two different temperatures of the mounting to which higher power transistors must be affixed to aid in the dissipation of heat. Since the temperature of the mounting would necessarily be raised somewhat above the ambient temperature by the relatively great amount of heat to be dissipated, a conservative design for use in ambient temperatures as high as 55 degrees C (131 degrees F) would probably be restricted by the $T_M = 70$ degrees C boundary.

Here load line No. 1, representing a resistance of $R_L = \frac{60}{0.75} = 80$ ohms, would develop an approximate power output of

$$P_o = \frac{60 \times 0.75}{8} = 5.6 \text{ watts}$$

Load line No. 2 would have a resistance of $R_L = \frac{40}{1.2} = 33$ ohms and be capable of developing approximately

$$P_o = \frac{40 \times 1.2}{8} = 6 \text{ watts}$$

of signal power output. No. 3's resistance is $R_L = \frac{20}{2.3} = 8.7$ ohms and its approximate power capability

$$P_o = \frac{20 \times 2.3}{8} = 5.7 \text{ watts}$$

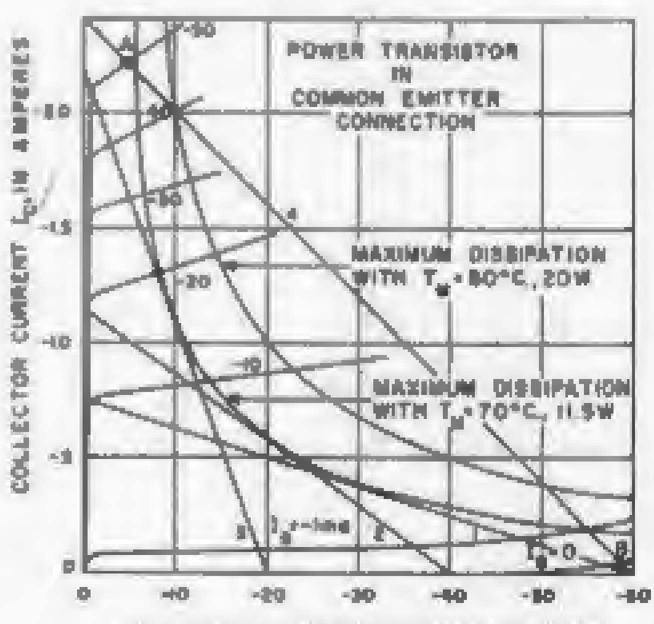


Figure 7.

Although all these load lines are capable of giving almost the same power output, it should be noted that the power input required to drive the transistor varies widely in the three cases.

Load line No. 1 requires a peak-to-peak input swing from 0 to 10 ma to produce maximum output, No. 2, 0 to 20 ma, and No. 3, 0 to 50 ma. If the input resistance is assumed to be constant the relative input powers required for full output will vary as the square of the current ratio or 25 to 1 from the No. 3 to the No. 1 load line, which is a difference in gain of 14 db.

Linearity

In the common emitter configuration neither the input circuit characteristic nor the field of the collector family is usually very linear. Because of the high current multiplication between the base and collector the base current is now relatively small. Thus the relationship between the input current to the base and the input potential has the shape of the low potential and current characteristic of Figure 2B. Here the same increment of potential gives larger and larger increments of current as the potential gets higher. The emitter family, on the other hand, shows smaller and smaller spacing between curves for the same increment of input current, as the higher values of current are reached.

These two effects tend to offset one another. Driving the input circuit from a greater than zero impedance generator tends to linearize it. If just the right combination of generator impedance, base bias potential, load resistance and E_{CC} can be found, distortion can theoretically be reduced to a minimum. However, when it is realized that the manufacturers' tolerances for maximum and minimum values of α_e for a given type of transistor are sometimes in ratio greater than 3 to 1, one concludes that careful design work here is unwarranted and that reliance must be placed in negative feedback to reduce distortion, as well as to show a match to the load impedance.

A Reminder

Perhaps it would be well to remind the prospective experimenter that if an output transformer is interposed between the load and the emitter circuit, E_{CC} should not exceed one-half the maximum rated emitter potential. This is because as the current in the transformer is reduced below the bias value, the collapsing field will generate an emf which adds to E_{CC} producing a total potential approximately twice its value.

One Word on Switching

When the transistor is used in switching, a load line such as No. 4 of Figure 7 may be employed, providing the transition from the "on" condition represented by point A to the "off" condition represented by point B is made quickly enough and infrequently enough so the average dissipation remains below the allowable. When a load line such as this is used, precautions must be taken to avoid the possibility of the potential at the base ever getting "stuck in the middle" even if the control circuit goes short or open.

The Common Collector Circuit

The last circuit to be dealt with is the common collector configuration which is shown by Figure 8. The circuit as drawn at A makes it clear that the collector is actually the common element, while the arrangement at B shows more clearly that R_L is common to the input and output circuit.

The bias potentials and the potential drop across R_L have polarities as marked. If the instantaneous signal potential has the polarity shown it will increase the current flow in the transistor causing e_{RL} to increase. This increase in e_{RL} subtracts from the total potential around the input loop and is, therefore, degenerative and may approach but not equal e_g. This reveals the common collector circuit to be an emitter follower. The virtues of this type of circuit are high input resistance, low distortion and, with proper design, the ability to present a matching resistance to the load.

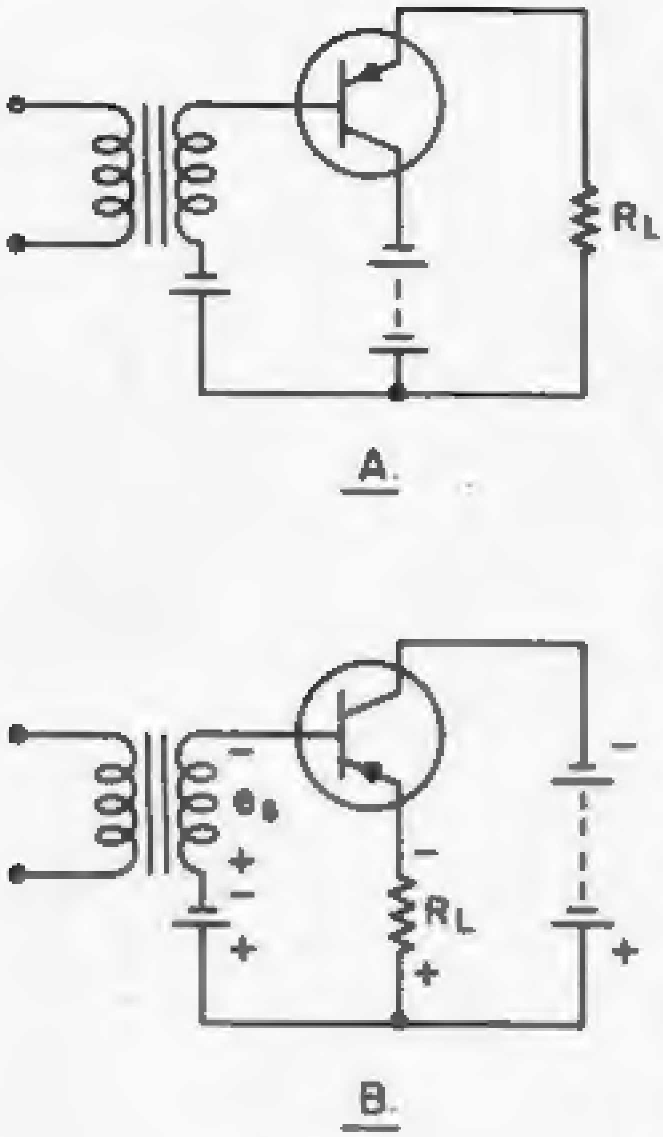


Figure 8.

Thermal Runaway

Transistor constants tend to vary with temperature. One of the most widely varying is the collector diode reverse or leakage current I_{co}. This current, which in a small germanium transistor at room temperature may be a few microamperes and in a high-power unit as high as a milliampere or more, may tend to be twenty or more times this value at higher operating temperatures. To make matters worse, in the much used common emitter circuit, aside from the modifying effect of circuit considerations, it tends to be multiplied by α_e. Unless the circuit considerations are such as to forestall this event, the rise in current may be great enough to bring the circuit to an inoperative condition. Another unfortunate possibility is that the increased heating due to the increased current will initiate a vicious circle in which the increments of each factor are constantly greater so that thermal stability will never be reached and the transistor will destroy itself. This phenomenon is known as "thermal runaway."

A number of ways of mitigating this effect are described in detail in the standard texts. Two of the simplest are shown by the circuits in Figure 9. Both of these depend upon d-c feedback.

In the circuit shown at A the biasing potential for the base is obtained by connection to the collector. If the average collector current tends to increase, the drop in potential across the load resistance will tend to reduce the bias on, and the current in, the base circuit. This reduction is multiplied by α_e and will hold in check the amount by which I_c tends to increase.

The arrangement at A cannot be used when the load has a low d-c resistance as in the case of the primary of an output transformer. In the circuit shown at B, which works under any circumstances, R_1 and R_2 should be of as low resistance within reason as the power supply can afford without appreciably lowering the input resistance of the circuit. This will

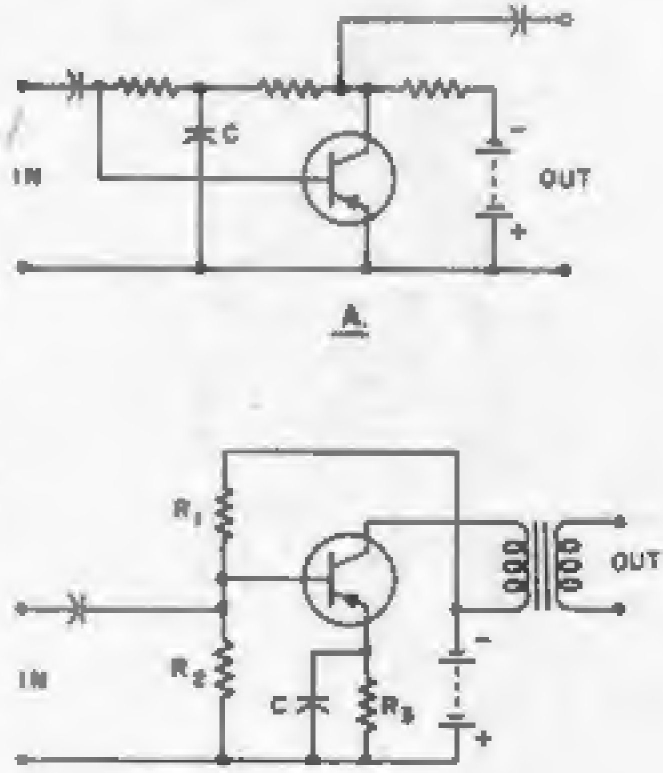


Figure 9.

fix the potential at the base and the current in R_3 will reach equilibrium when the potential drop across it is equal to the potential across R_2 minus the base-emitter potential required to cause this particular value of current to flow.

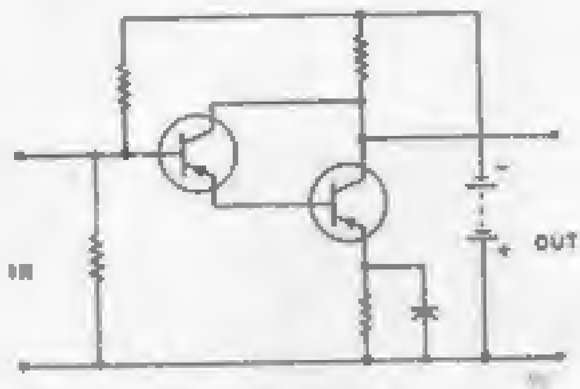
The greater the value of R_3 the more control that will be exerted. The ratio of R_1 to R_2 and the magnitude of R_3 will fix the bias value of the current. Any tendency for the current through the transistor to increase will tend to reduce the potential between the base and emitter and thus the current, whence the effect will be as before.

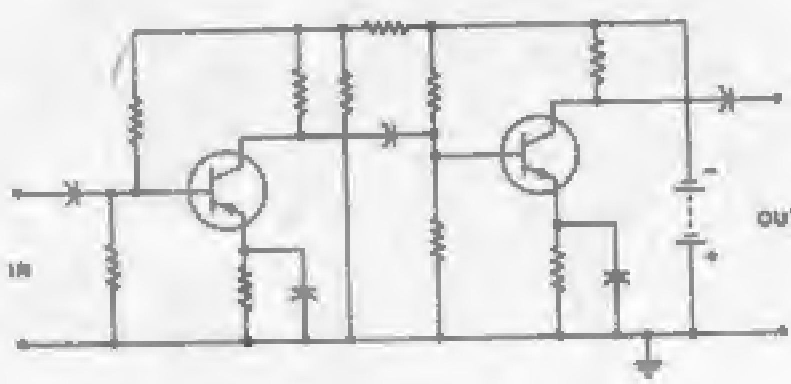
Elimination of the bypass capacitors C will allow negative feedback at the signal frequency to take place and reduce the gain. Feedback in the circuit as shown at A reduces the input and output resistance, the type shown at B causes them to increase.

Multistage Circuits

When more gain is required than can be obtained from a single transistor additional units may be connected in series cascade until the required characteristics are obtained. It is customary to use as the first transistor as small a one as is available which will comfortably handle the input signal level. The following one's capabilities should bear a similar relationship to the output of the first, and so on until a transistor with the necessary power output is reached.

This is because, all other things being equal, the higher the power a transistor is able to handle the lower its upper limit of frequency response and the greater its I_{co}. As regards the first item, the disadvantages of using large transistors throughout are obvious if as good as possible high-frequency response is an objective. High I_{co} makes bias point stabilization more costly of battery power and possibly of components as well.





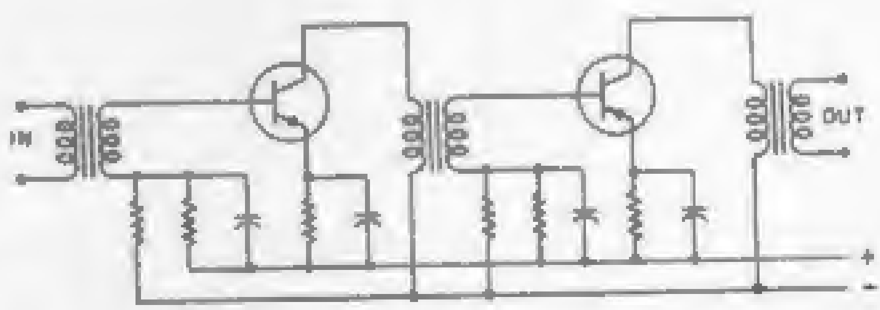


Figure 10.

Transistors may be coupled to one another either directly, by means of RC networks, or by transformers. Because there is no current gain in a grounded base stage it should not be direct or RC coupled to another grounded base stage or a grounded emitter stage. (This is not necessarily true of point contact type.) Grounded emitter stages may be coupled by any of the three methods and any of

the configurations may be coupled by transformers. Unless as good a match can be achieved without it, greatest gain will be obtained through the use of a transformer which matches the "maximum power gain load line" that can be laid in on the collector family, to the input resistance of the next stage. Figure 10 shows circuit arrangements of two-stage amplifiers using each of the types of coupling mentioned.

Conclusion

The reader must understand that Mr. Pierson's paper and this one only scratch the surface in their respective fields. Considering the early state of transistor development, present knowledge is far advanced and indicates that the possibilities and problems in the future development of the transistor and its circuits are both enormous.

Harry C. Likel received the degree of Electrical Engineer from Brooklyn Polytechnic Institute in 1930. His first employment was in the development laboratory of the Pacent Electric Company where he worked on the design of radio receivers and components, theatre sound equipment, and so forth. He later transferred to Pacent Engineering Corporation, of which he was Chief Engineer when he resigned. In 1940 he went to the Postal Telegraph-Cable Company, and on its merger with Western Union was assigned to the Equipment Research Division and later to the Radio Division. For 17 years Mr. Likel taught in the evening at Pratt Institute, The Cooper Union, and Brooklyn Polytechnic where he attained the rank of Adjunct Professor. He is at present a member of the AIEE committee on Radio Communications Systems, a Senior Member of IRE, a member of AIEE, and holds a registered New York State Professional Engineer's license.

Transmission Speeds and Pulse Lengths of Commonly Used Five-Unit Start-Stop Printing Telegraph Codes

In order to provide a source of ready reference for engineers and maintenance personnel who frequently require information concerning the pulse lengths and speeds of the many different five-unit start-stop teleprinter codes used by Western Union and interconnecting communications companies, the table reproduced on the following page has been prepared. This table gives useful data on all of the five-unit start-stop teleprinter codes used by Western Union, as well as data on some codes which are not now used in our services but which are frequently encountered in international communications.

When the five-unit Baudot code was originally adapted for use with start-stop telegraph apparatus by adding a start pulse and a stop, or rest, pulse, the start and stop pulses were made the same length as the code pulses, resulting in a code having seven pulses of equal length. The term "seven-unit code" has been generally adopted to describe such a code. A more accurate but less commonly used term is "a five-unit code with a seven-unit pattern."

It was found that the operating margin of some of the early printing telegraph apparatus could be improved by making the stop pulse longer than the start and code pulses. Consequently, the rest pulse length was increased to 1.42 times the length of a code pulse. The question is often raised as to how an odd figure such as 1.42 came to be chosen. One plausible-sounding story is that the engineer who designed the first faceplate distributor intended to make a 7.5-unit faceplate. He calculated the angular length of the code and start segments, then turned over the job of laying out the faceplate to a draftsman, with instructions to provide slots between adjacent segments. The draftsman laid out the faceplate as instructed without shortening the angular length of the code and start segments to compensate for the slots. The rest segment was then shortened to compensate for all of the slots and it turned out to be 1.42 times the length of the other six segments. The first models of the faceplate were made before the error was discovered and it was decided that it would be simpler to adjust the motor governor to obtain the speed necessary to give the correct length code pulses than to make a new faceplate. If this story is true, the error proved to be a convenient one when 1800-rpm synchronous motors came into wide use. In order to obtain a 7.5-unit code pattern with the 22-millisecond code pulses already in use the speed of the transmitting shaft would have to be $60 \div (0.022 \times 7.5) = 363.63$ rpm. With the small gears used in teleprinters, there is no practical gear ratio which will give this speed when an 1800-rpm motor is geared down by means of a single pair of gears.

In every code shown in the accompanying table the start and five code pulses are all equal in length, but the rest pulse length may be 1, 1.42, or 1.5 times the code pulse length. All speeds and pulse lengths given in the table are nominal. The actual lengths may vary somewhat due to necessary compromises in gear ratios and to rounding off of calculated angular dimensions.

The average number of words per minute shown in the third column is obtained by dividing the speed in operations per minute by six, on the assumption that an average word requires six operations of the teleprinter, including the space between words and any other nonprinting function of the teleprinter such as letters shift, figures shift, carriage return, and line feed.

The fourth column gives the speed in

FIVE-UNIT START-STOP PRINTING TELEGRAPH CODES

CODE PATTERN (TOTAL NUMBER OF PULSES PER CHARACTER)	NOMINAL SPEEDS AND PULSE LENGTHS: TRANSMITTING SPEEDS: OPR'NS PER MINUTE	AVERAGE WORDS PER MINUTE	BAUDS	PULSE LENGTHS IN MILLISECONDS: START AND FIVE CODE PULSES	REST PULSE	REC'V'G SHAFT SPEED IN RPM	MILLI SEC'S PER CHAR-ACTER	WHERE USED
7.42-Unit	368*	61.33	45.45	22	31	420	163	Bell System—U.S.
7-Unit	390*	65	45.45	22	22	420	154	Western Union—U.S.
7.5-Unit	400**	66.67	50	20	30	461.5	150	C.C.I.T. Standard—Europe
7.42-Unit	404**	67.33	50	20	28.4	461.7	148.4	U.S. Military for Inter-operation with Allies
7-Unit	428.6**	71.43	50	20	20	461.5	140	Former C.C.I.T. Standard—Europe
7.42-Unit	460	76.67	56.88	17.57	25	525.7	130.43	U.S.—All Commercial and Military Users
7.42-Unit	600***	100	74.2	13.47	19.18	685	100	U.S.—All Users
7-Unit	636***	106	74.2	13.47	13.47	685	94.3	U.S. Military—Limited Use

*These two codes are compatible
**These three codes are compatible
***These two codes are compatible

bauds for each code. A baud is the reciprocal of the length in seconds of one code pulse, in other words, a baud is the maximum rate of transmission in pulses per second. Thus, for a code with 22-ms pulses the speed in bauds is $1 \div 0.022 = 45.45$. In general, two codes are compatible if their speeds in bauds are equal and the receiving shafts of the two teleprinters operate at the same speeds.

The abbreviation "C.C.I.T." given in the last column stands for the Consultative Committee on International Telegraph, an organization devoted to development of recommended international standards for telegraphy. The standards recommended by this Committee have been adopted in most European countries.

Until very recently the use of a 7-unit code at speeds higher than 390 opm had been considered inadvisable because of the reduced margin of operation expected with a short rest pulse. The selector armature of a teleprinter must be in the marking position at the time the receiving shaft completes a revolution so that the receiving shaft will stop briefly at the end of each revolution and thus remain in start-stop synchronism with the transmitting apparatus. On a teleprinter geared for 600 opm, the receiving shaft rotates at 685 rpm and the time required for one revolution of the shaft is $60 \div 685 = 0.0876$ seconds. The length of one pulse at 600 opm is 13.47 ms and the length of a 7-unit signal train compatible with this code is $13.47 \times 7 = 94.29$ ms. Thus, the take-up time of the receiving shaft clutch must not exceed $94.29 - 87.6 = 6.69$ ms. If the take-up time does exceed this value, the shaft will not complete a revolution before the end of the rest pulse and the receiver will be out of synchronism during the following signal train.

When a requirement for a 7-unit code with 13.47-ms pulses developed, tests were made on Model 28 teleprinters and printer-perforators to determine the practicability of such a code. It was found that the receiving apparatus performed satis-

factorily at this speed with ample margin of operation. The code was then adopted for this special requirement. This code is the last one listed in the accompanying table.

It will be noted from the table that the speeds frequently referred to as "60-word" and "75-word" are actually 61.33 and 76.67 wpm, respectively. Also, a 7.42-unit code pattern is frequently referred to as a "seven-and-a-half-unit" code. Use of such "verbal shorthand" in referring to the speeds and code patterns occasionally leads to misunderstanding and should be avoided. It is preferable, for example, to designate the speed in operations per minute.

Start-stop teleprinter codes which contain five intelligence pulses are referred to as five-level, five-channel, or five-unit codes. All three of these terms mean exactly the same thing. Intelligence pulses are also frequently referred to as "bits" and the baud speed as "bits per second."—Fred W. Smith, Assistant to Apparatus Engineer

Equipment to facilitate switching telegrams from local lines to trunks in an experimental installation at Detroit was assembled and wired in the precision apparatus shops of the Western Union electronics research laboratories at Water Mill, N. Y. Teleprinter conversions were made at Detroit. Other work was done at the company's Chattanooga and Jersey City shops.

WILLIAM B. BLANTON, Director—Planning—Plant and Systems

Some Aspects of Telegraphic Data Preparation and Transmission

Principles and equipments long known and widely employed in the telegraph industry have demonstrated their value for original preparation and transmission of business data, and for directing, switching and sorting these data at telegraph or computer centers. Because most present day telegraph networks operate with 5-level punched paper tape, particular interest centers in a 5-level transmission system arranged for detecting transmission and equipment errors, and automatically assuring a correct received copy.

THE enormous growth that is taking place in the electronic generating, processing, and recording of data is making new demands on telegraphic communications. Because of the growing volume and the statistical nature of data, these demands stress economy and accuracy.

Preparation of Data for Transmission

Accuracy in the telegraph transmission of data must start with the original preparation of the data in a character-coded form for introduction into the transmission system. If this is done from the storage of a machine, suitable electronic circuitry can be provided to insure accuracy. In most cases, however, human effort is required in transcribing from the original typewritten forms and reports. It is telegraph experience that human errors involved in this original transcription far outnumber subsequent equipment and line transmission errors. Unfortunately, they are the most difficult to detect.

One technique which holds considerable promise for practically eliminating transcription errors is electronic character sensing. In this technique, the characters in the original copy are photoelectrically sensed and recognized, and a punched tape is prepared automatically. Excellent results have already been obtained where strict controls can be applied to the original printed copy, but considerably more work remains to be done before the flexibility, economy and reliability are obtained that are needed in general telegraph applications.

System designers are constantly trying to achieve accuracy and economy in the transcription of data into a form suitable for transmission by transferring to machines as many of the fixed and repetitive functions as is economically and technically feasible. Telegraph equipments and techniques are widely applicable in this field. In many organizations the mechanization of office paper work is being accomplished by maintaining files of prepunched tape containing fixed data and control code combinations. These tapes are used to prepare a printed document and a complete tape of each new transaction. It is necessary to insert by keyboard only the variable data pertaining to the particular transaction. The complete tape can be transmitted to other points in the organization for producing partial or complete tapes and printed copies. At these points, the new tapes can be used for processing the transaction further, any additional data that may be needed being added by keyboard.

Edge-punched cards which have the telegraph code punched along one edge are also being used for the storage of data. The cards are more durable and are filed more easily than punched tape. At present they are only punched but plans are under way for equipments that will both punch and print the cards. Magnetic discs

A paper presented before the National Convention of the Armed Forces Communications and Electronics Association in Washington, D. C., May 1957

of the type used on dictating machines appear to have advantages where small amounts of data must be stored and selected at random for preparing documents. The discs are durable, have a fairly large storage capacity, can be filed along with the documents, and can readily be erased. Development work is now in progress on this type of equipment.

In some instances of transcribing data, the process is essentially that of entering variable data on one of a number of fixed forms. One way of mechanizing this carriage position register that indicates each of its 72 positions, and a line register that indicates each of 20 lines on the form. Sixteen different line programs can be set up on the plug board.

At the top of Figure 1 is shown part of the printed form, and below is shown the tape produced. The line programs will cause the character or a combination of characters shown below the tapes to be inserted automatically when the printer carriage arrives at designated positions. By means of the line position register, any

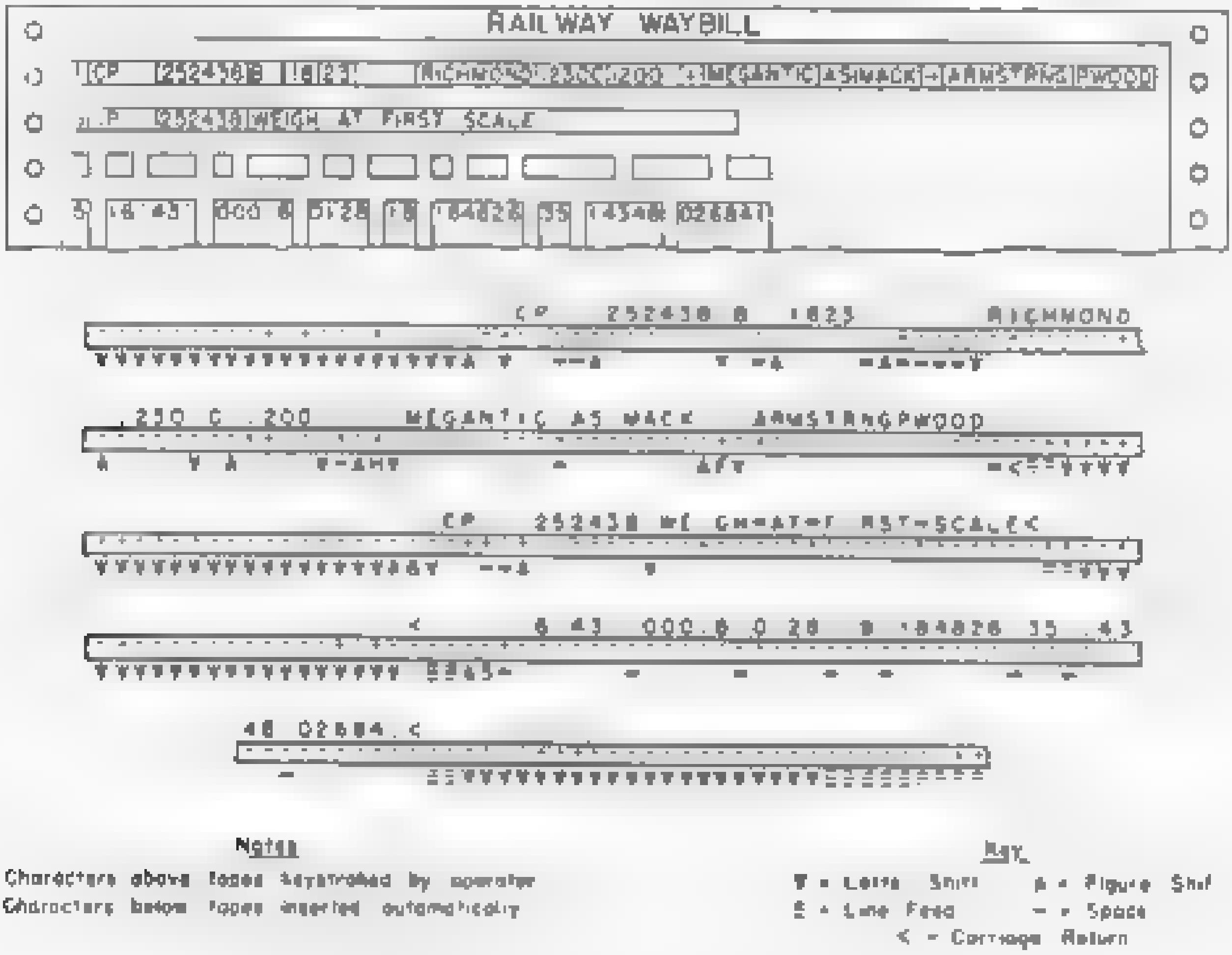


Figure 1 Railway waybill form and printed perforated tape

process is to provide for each type of form a removable program panel that will cause the fixed information to be entered automatically.

A prototype setup has been made, consisting of a telegraph page printer, a printer-perforator, a transmitter, and a plug board apparatus, for off-line use in typing a printed form and at the same time preparing a printed perforated tape for use in further processing or transmission. The printer is provided with a line program can be made effective at any desired line on the form. Generally, several lines on a form will use the same program. Inserted characters may advance the printed carriage to the next field on the form, or may convey any kind of fixed information. If desired, characters may be punched in the tape only, for use in further processing. The operator key-strokes only the variable information, shown above the tapes, thus reducing the possibility of human error

Line Facilities for Data Transmission

Before the data processing revolution, telegraph transmission was mostly of discrete messages, prepared by humans and read by humans. Telegraph transmitting and receiving equipments capable of speeds of 65, 75 or 100 words per minute with the 5-level telegraph code were economically satisfactory for that traffic. Now, with machines producing and consuming data in increasing amounts, there is a growing need for transmission facilities that are economical for the bulk transmission of data. Usually this requirement is expressed in terms of "high-speed data transmission." In most cases, however, high speed is not the essential element but rather is the generally accepted means of meeting the requirement.

The 3-kc voiceband is the vehicle for all of the trunk or long-haul circuits in the present Western Union plant. Each of these 3-kc bands is divided into two half-bands. Each half-band has a useful spectrum from approximately 225 to 1625 cycles and is frequency-divided into nine telegraph channels that are suitable for speeds up to 100 words per minute

Since the half-voiceband is available throughout its plant, Western Union has turned its attention to the development of suitable terminal modulating and demodulating equipment for using these half-bands for the high-speed transmission of data. This work is nearing completion, and tests indicate that a signaling speed of about 400 cycles per second is practicable. In computer language, this is 800 bits per second, or somewhat more than ten times the signaling speed of a 100-word-per-minute telegraph channel.

In addition, plans are under way for providing a telegraph channel of about 1/8-voiceband width, which will be suitable for a signaling speed of around 100 cycles per second, or 200 bits per second. Such a channel can be used by one IBM transceiver circuit operating at the rate of 11 cards per minute, or for the transmission of 7-level paper tape at the rate of 200 words per minute.

Western Union pioneered in the development and application of frequency modulation for telegraphy. Its trunk line plant comprising several million channel miles is operated by this method. As a result, the company enjoys a unique resistance to errors due to changes in the transmission characteristics of the voiceband and errors due to fortuitous interference.

Regenerative repeaters are not normally required even though several sections of carrier channels are operated in tandem. Therefore, 6, 7 and 8-level or even higher level data codes can readily be transmitted over line facilities that are in general use for 5-level code transmission.

Accuracy in Data Transmission

Error detection and assuring accuracy in transmission is a problem that is not unique to long distance transmission of data. As is well known, computers and other data processing systems that transmit data within the same machine, and possibly to other machines a few feet away, are replete with error detecting arrangements. Transmission systems are subject to more extraneous interferences but even if these were not present it would be necessary to protect against equipment and component failures. Many schemes have been devised for providing error detection and invariably they require redundancy; that is, the transmission of more information than is necessary to convey the intelligence.

Examples of vertical checking codes in which the redundancy is individual to each character are the odd or even parity codes, and the codes having a fixed ratio of marking and spacing pulses. The parity codes may be 5, 6, 7 or 8-level codes, but in any case each valid code combination has an odd number of marking pulses when an odd parity check is employed, or an even number of marking pulses for an even parity check.

It is almost universal practice for electronic computers that operate with both alphabetic and numeric characters to employ a 7-level code. Six of the levels define the character and the seventh is for the

purpose of obtaining a parity check. Unfortunately, the assignment of characters to the code combinations varies for practically every computer manufacturer

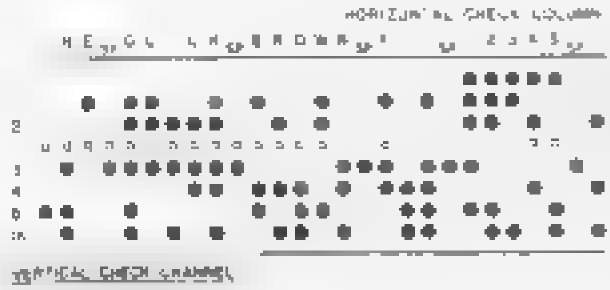


Figure 2 Vertical and horizontal parity check

Examples of the fixed ratio codes are the familiar 8-level code where all valid code combinations have four marking pulses, the 7-level code where all valid code combinations have three marking pulses, and the 5-level code where all valid code combinations have two marking pulses.

While the fixed ratio codes are more redundant than the parity codes, they are less subject to compensating errors. For example the loss or gain of two pulses is undetected by parity codes but is caught by the fixed ratio code. Both types of code fail to detect loss or repetition of complete characters. A common method of guarding against this is to organize the data into groups having a definite number of characters and transmit a signal after each group. Both types of code fail to detect a loss and gain of a pulse within the same character One method of increasing the effectiveness of parity codes is shown in Figure 2. A 7-level odd vertical parity check is combined with horizontal check After each block of data there is inserted a character chosen so as to make each of the seven levels have odd parity

Transmission within a computer is usually on a parallel basis. Each level of the code is transmitted by components individual to the level Faults are generally confined to one level The vertical parity code is very effective for this mode of operation.

Over a communication line, code pulses are transmitted in serial form Fortuitous faults are very apt to affect two or more adjacent pulses within a character Some tests made over a marginal line indicated that 7-level vertical parity checking detected about 90 percent of the errors. A horizontal parity check applied to groups of approximately 60 characters detected approximately 99 percent of the errors. It is reasonable to expect that a combination of the two would have been almost 100 percent effective

Clearly there are many problems to be solved before a telegraph switching system can be designed which will accommodate these various codes and checking systems and yet have the general applicability of present systems that operate on the 5-level code. Considerable thinking is being done along these lines and, probably more important, a RETMA committee composed of representatives from communication companies and computer manufacturers is attempting to standardize code practices. Meanwhile, immediate demands for the transmission of the various codes and checking systems will be met by conversion units or custom tailored systems.

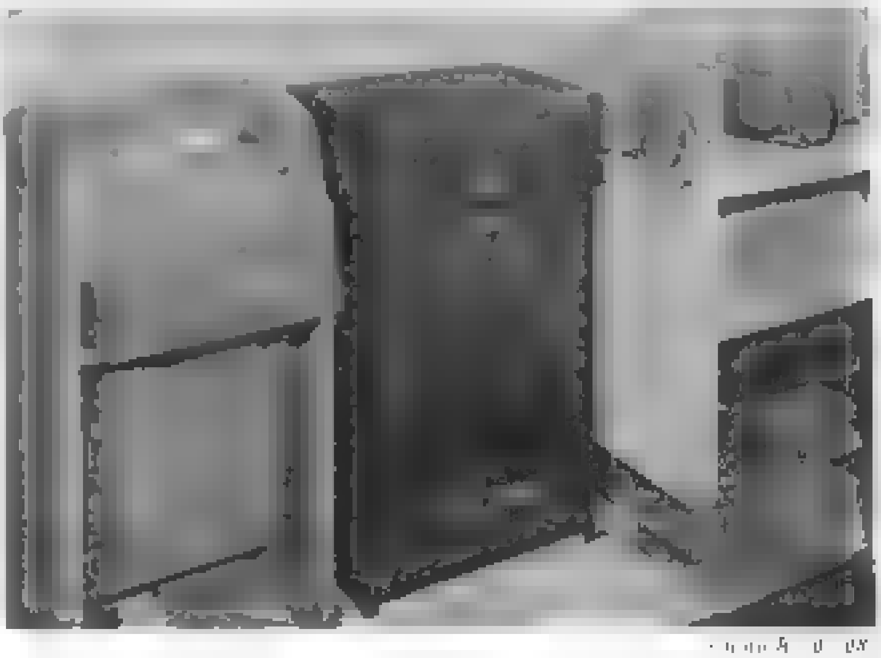


Figure 3 Equipment used at one station of a multistation system

Multistation 7-Level Data Transmission with Error Detection

Figure 3 shows equipment used at one station of a recently developed multistation system which will permit a central station and as many as eight outstations to share one line circuit. The equipment transmits tape perforated with a 7-level odd parity checking data code, and checks each character for parity at the receiving station. Commercial Controls tape readers and punchers and Model 28 printers are used in the system.

To send a data message from any outstation, one inserts the 7-level tape in the reader and depresses a request button. When the circuit is idle, the station is automatically connected to it and the message is transmitted into the central station. The central station can similarly send a message to any outstation by depressing the appropriate push button. When the circuit is idle, the outstation will be selected automatically and the message transmitted.

As each received character is punched in the tape, an odd parity check is made. If the check is not met, the transmitter is stopped, alarms are actuated at both the sending and receiving stations and the printers are cut into the circuit. The operators use the printers to determine what action to take. Generally the tapes are set back to the same point, and at the receiving end the errored portion of the message is "rubbed out" by overpunching. Then transmission is resumed.

5-Level Code Transmission with Error Detection

The foregoing illustrates a method of error detection employing a 7-level code. However, the public telegraph system and most private wire networks—both commercial and military—operate with the 5-level telegraph code. Since this is the common telegraph language there are a large number of business machines and other data equipments in daily use that function with 5-level tapes. Telegraph Company engineers have, therefore, devoted much of their effort to developing methods of error detection and correction in 5-level code transmission.

Before considering error correction, an acceptable method of error detection for the 5-level code must first be developed. As a background for the method now to be described, a successful application of a programmed accuracy check will be reviewed.

When data consist of groups of figures, adding each group and transmitting the total provides a very effective method of error detection. The receiving station performs the same addition and determines whether its total agrees with the transmitted total. This method of error detection is limited to numeric information, but it provides an effective foundation for the development of a method for checking both alphabetic and numeric characters.

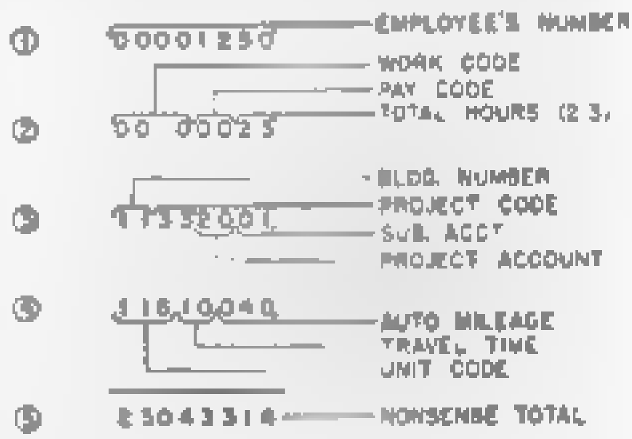


Figure 4. Payroll and management control data

Western Union is making extensive use of this type of accuracy check in transmitting its own payroll and other management control data over its public message system. In field offices perforated tapes containing operating data entirely in numeric form are prepared on add-punch machines. These adding machines prepare a printed tape and a perforated tape. Figure 4 shows the information extracted from an employee's daily work report. All of the information is entered into the add-punch machine in four groups of digits. A "nonsense" total is calculated and recorded automatically on the printed tape and in the perforated tape.

The tapes are then transmitted to division headquarters where they are converted to punched cards. The cards are run through computers for the automatic preparation of payrolls and management control reports. To insure accuracy the computer also adds the numbers in each group and compares the total with the transmitted nonsense total. If they do not check, the card is rejected and a rerun is requested.

The nonsense total method of error detection has proved to be very satisfactory in practice, and an error which was not detected by this check has yet to be discovered.

EDIT

Western Union is developing a system that will provide error detection and correction for data consisting of both alphabetic and numeric characters. This system employs a totaling technique somewhat similar to the nonsense total in that the marking pulses in a line of data are totaled on a weighted, binary basis. The system employs equipments at the sending and receiving ends of a circuit for providing error detection and correction while transmission is taking place.

The transmitting equipment can send tapes already having checking information or can automatically insert checking information after each line. In either case, the transmitter will stop after sending the checking information for each line of data to await instructions from the receiving station. The receiving equipment checks each line of data with its associated checking characters. If the check indicates no error, the transmitter is signaled to send the next line. If an error is indicated, the reperforator deletes the errored line from the tape and signals the transmitter to repeat the line of data. This type of system has been christened EDIT, which has a significance other than its literal meaning — it is "Error Deletion by Iterative Transmission."

Figure 5 shows the prototype EDIT reperforator used at the receiving station. It is arranged to handle 5, 6, 7 or 8-level tapes. It has both punching pins and sensing pins which are one character apart. Immediately after a character is received and punched, the tape is advanced to its next position, where that character can be read by the sensing pins. In this manner characters are read for error checking purposes. To "rub out" a line of data having an error the tape is back-stepped with all punching pins operating to overpunch each character. The sensing pins determine how far to back-step. The EDIT transmitter also is arranged for handling 5, 6, 7 and 8-level tapes. It can step and read the tape either forward or backward.

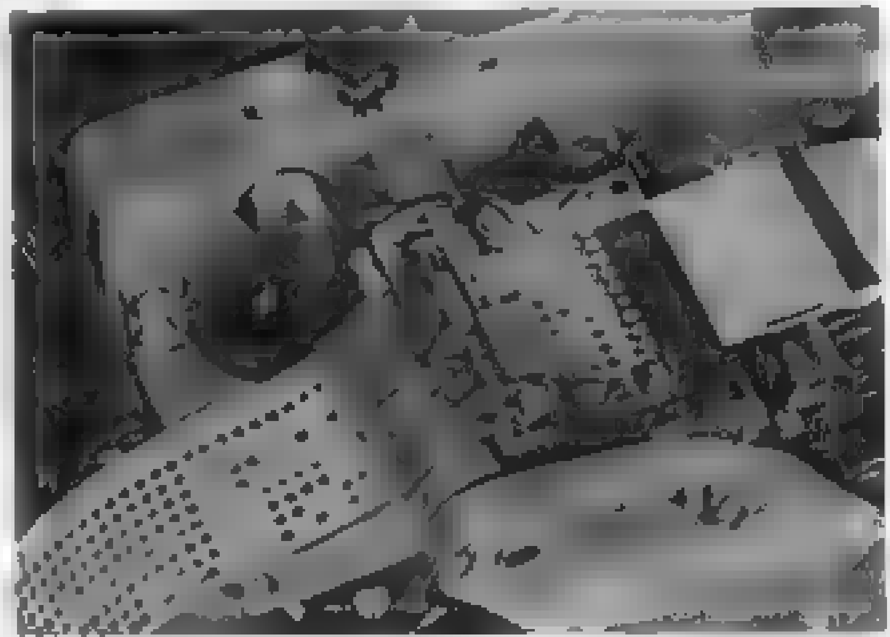


Photo M 4915

Figure 5. Prototype EDIT reperforator

The reperforator and transmitter operate on a parallel input-output basis. Electronic distributors are associated with them for serial operation over a telegraph circuit. They may be operated at regular telegraph speeds of 65, 75 and 100 words per minute, or at higher speeds up to 200 words per minute.

With suitable associated circuitry, the EDIT equipments can be used for error detection and correction in the transmission of any of the 5, 6, 7 or 8-level code

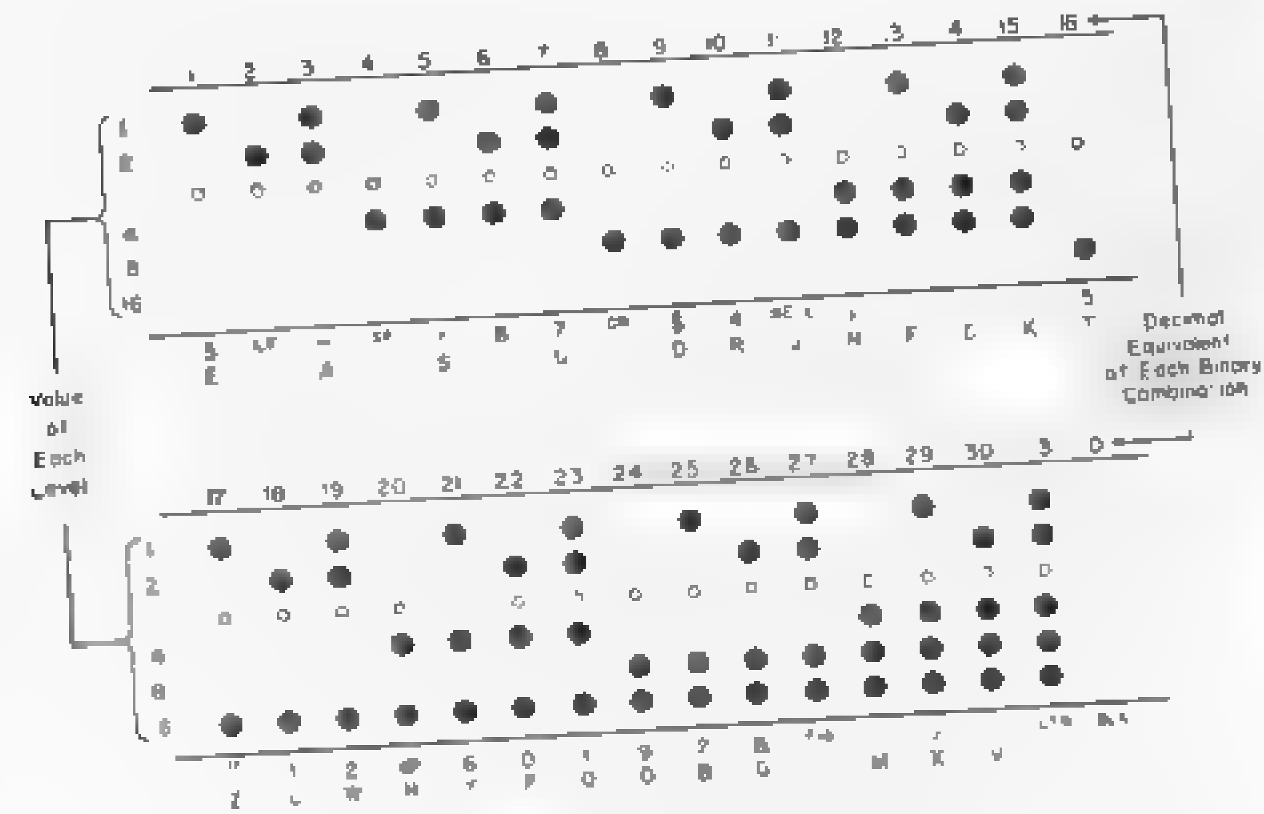


Figure 6. 5-Level telegraph code

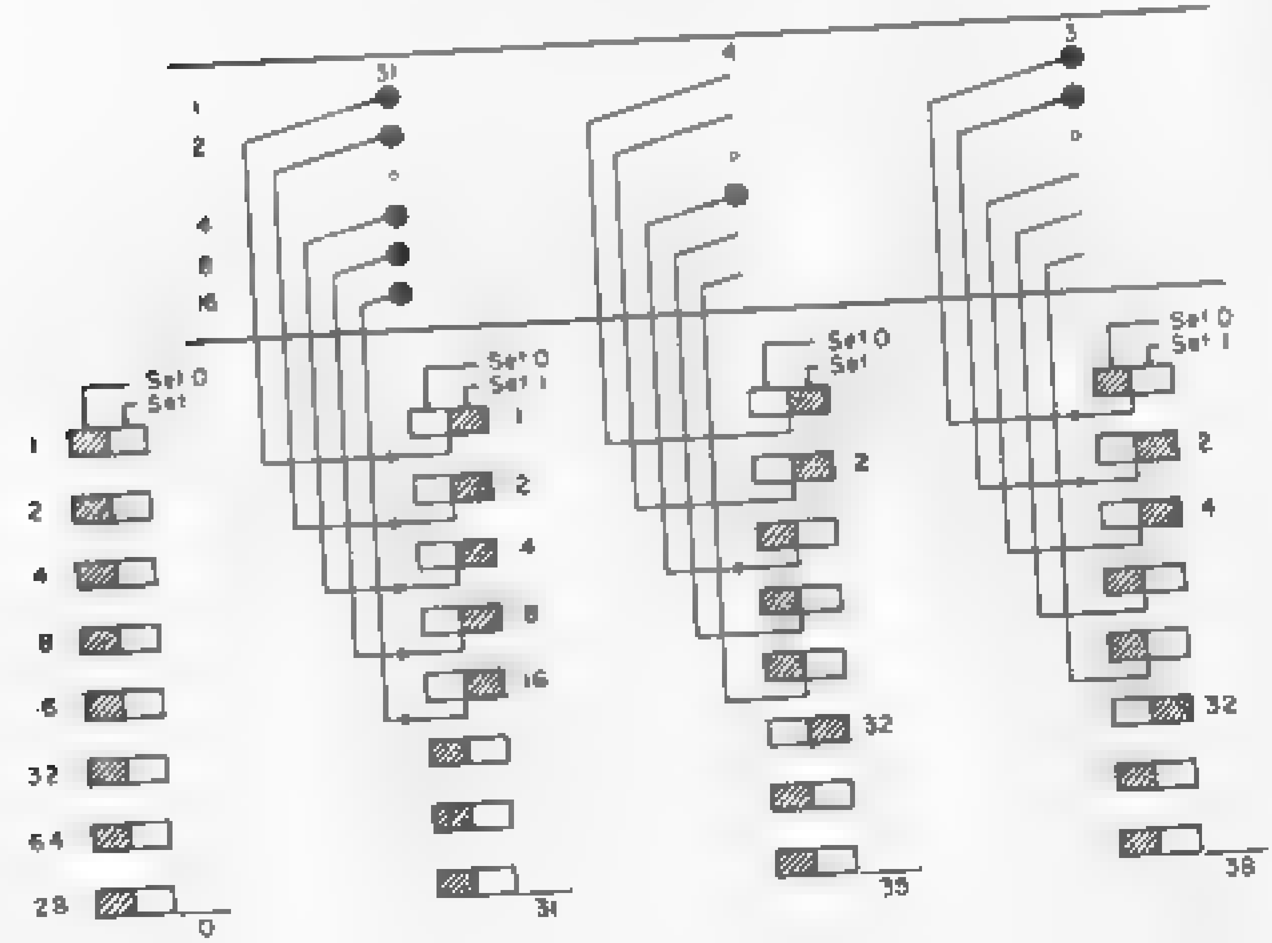


Figure 7 Counting binary codes

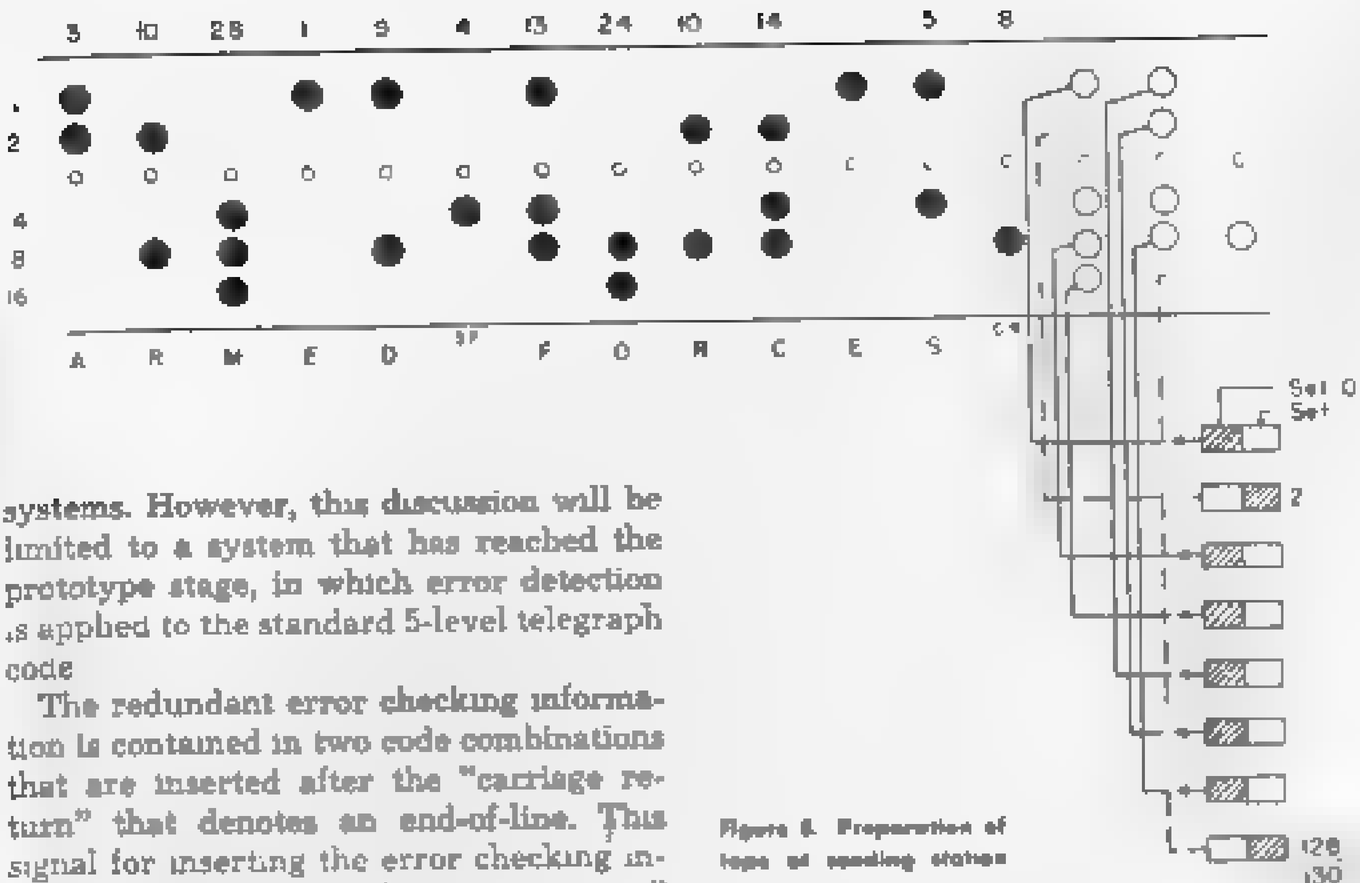


Figure 8. Preparation of tape at sending station

systems. However, this discussion will be limited to a system that has reached the prototype stage, in which error detection is applied to the standard 5-level telegraph code

The redundant error checking information is contained in two code combinations that are inserted after the "carriage return" that denotes an end-of-line. This signal for inserting the error checking information could be two "carriage returns" or, for that matter, any character or combination of characters that is not used for data characters.

The two error checking characters carry the binary total, on a modulus of 256, of all the code combinations in a line of data.

Figure 6 shows the 32 combinations of the 5-level code. At the bottom of each combination appears the character assignment generally used in telegraph service. Above each code combination is shown its binary value expressed as a decimal number

The method of accumulating the binary total of all the code combinations in a line of data is quite simple. The different valued pulses of each code combination are fed into the corresponding stages of a binary counter. As shown in Figure 7, the first character has five marking pulses, which will cause the first five stages of the counter to set from zero to one, giving a total count of 31. The next character has only a third marking pulse. This resets the third stage to zero, which in turn causes the fourth and fifth stages to reset to zero. The resetting of the fifth stage to zero causes the sixth stage to be set to one, thus giving a total of 35. The next character has a first and second marking pulse. While the pulses are essentially fed into the counter in parallel, varying degrees of delay, measured in microseconds, are included in the five wires so that the pulses actually arrive in the counter one at a time.

It was desired in the checking system to restrict the binary counter to eight stages. Thus the counting is on a modulus of 256 since each time the counter passes through a count of 256, it starts over at one.

In Figure 8 we see the organization of a line of data (shown as black circles) with its checking characters (shown as open circles). The binary total of the line equals 130 which is registered in the "one" side of the counter. However, the read-out is made from the "zero" side of the counter which is set to the complement of 130. The first four bits of this complement are transmitted as the first, second, fourth and fifth pulses of the first checking character. The last four bits are transmitted as the first, second, fourth and fifth pulses of the second checking character. The third pulses of the two checking characters are always transmitted as marking pulses.

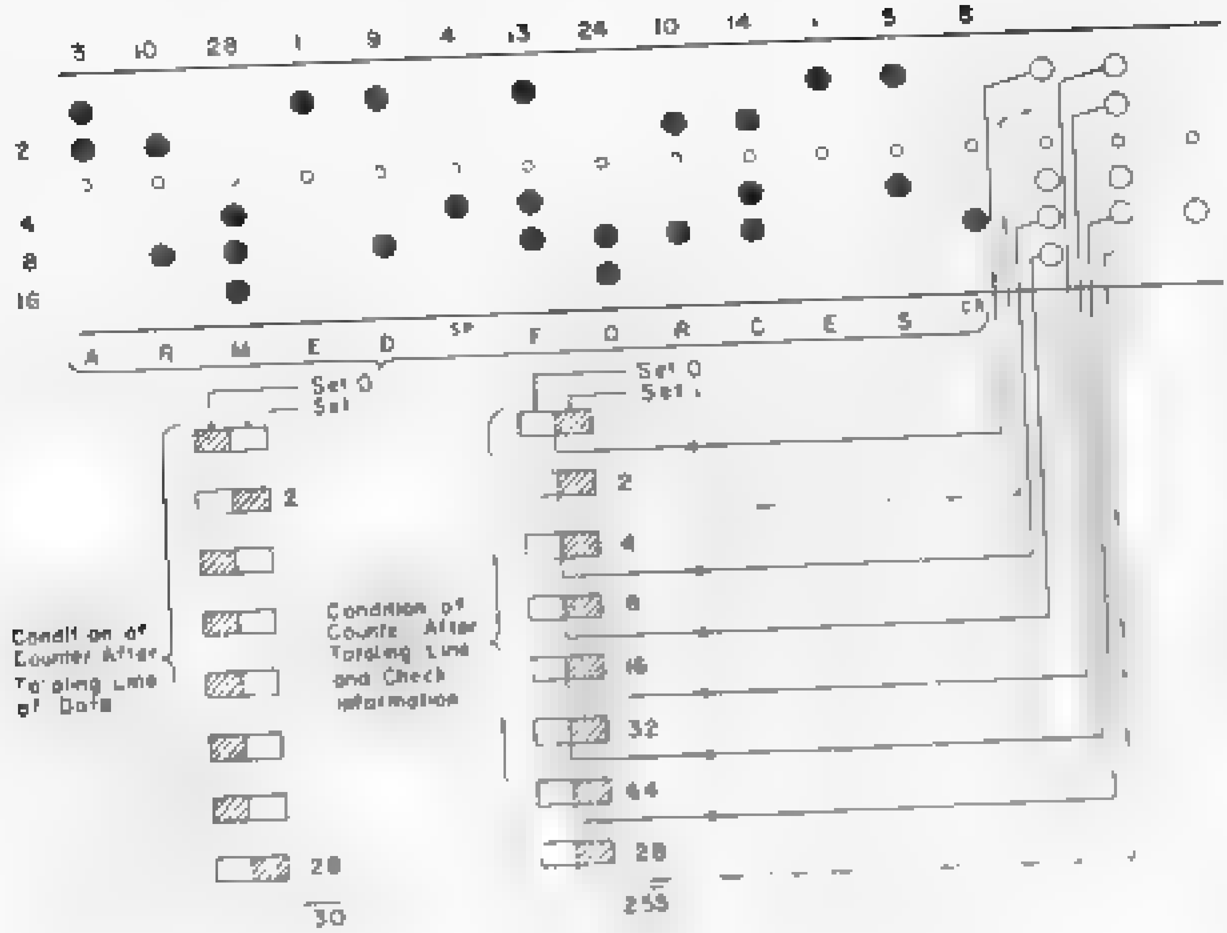


Figure 9 Checking at receiving station

This avoids certain undesirable code combinations such as "blanks," which are deleted by some switching systems, and two consecutive "carriage returns" or "Figure Shift H," which are end-of-message signals in some switching systems

The carriage return is added after the two checking characters for control purposes, as will be explained later

At the receiving end of the circuit, the sensing pins of the reperforator read the received characters into a binary counter If no error occurs in transmission, this counter should have the total of 130 for the line of text illustrated in Figure 9 Upon detecting the end-of-line signal the receiving equipment directs the eight bits containing the checking information into their respective stages of the counter Since these eight bits are the complement of the binary total, every stage will be set to its "one" condition if there are no errors. Any deviation from all stages being set to one will indicate an error

If no error is indicated, the transmitter receives a signal that causes it to send the next line of data If an error is indicated the transmitter receives an "error" signal that causes it to back-step its tape to the "carriage return" code that terminated the checking characters of the previous line of data Then upon a "ready" signal from the receiving station it repeats the errored line Meanwhile, the repertorator back-steps its tape and at the same time over-punches with five holes each character in the errored line When its sensing pins read the "carriage return" code that terminated the checking characters of the previous lines, it starts stepping its tape in the forward direction until it reaches unpunched tape, when it sends the "ready" signal to the sending station.

The binary total gives an extremely effective error detection system with low transmission redundancy Its totaling of the values of a group of characters gives protection against the loss or repetition of

complete characters. If an error is confined to one character in a line, it gives positive protection on errors that would be compensating in the parity or fixed ratio codes.

At the present time, EDIT is essentially for point-to-point communications. However, it is evident that it has possibilities for use on a complicated switching network for automatically detecting and correcting data transmission errors over each link of the system.

William B. Blanton, now Director of Planning—Plant and Systems, is a graduate of Virginia Polytechnic Institute who has been with the Telegraph Company since 1922. During this time he has been continuously employed in the development and engineering of circuits and equipment for switching systems that handle telegraphic communications. From both a supervisory and detailed design standpoint, he has taken an active part in the development of reperforator switching from the first trial installation at Ft. Worth in 1934 until the completion of the nationwide reperforator switching network described in various articles in TECHNICAL REVIEW. On becoming Switching Development Engineer in 1949 he took charge of the design and development of all new switching systems used in the Company's service and leased to private industry and the Armed Forces. Mr. Blanton was appointed Automation Engineer in the D & R Department in 1955. In 1956 he received the F. E. d'Humy Memorial Award "for his pioneering and continuing contributions to the development of Western Union Telegraph Switching Systems."

A. Z. MAMPLE, Assistant to Lines Engineer

Atmospheres in Which We Live — Safe or Dangerous?

An atmosphere which is explosive, toxic or oxygen deficient is downright dangerous. Explosive atmospheres in particular, which have been long recognized as a major industrial hazard, merit better understanding. Of direct interest in this discussion is a simple and accurate device to show when common atmospheric dangers are at hand, known as the Western Union Explosive Gas Detector and Oxygen Deficiency Indicator or, more succinctly, a Detector-Indicator.

THE AIR which we breathe is all too often taken for granted in the open, in the shop, in the office and in the home. Changing factors, especially those resulting from the actions of others, often affect us adversely unless we understand the nature of these factors. Ignorance of what the atmosphere contains frequently results in serious impairment to one's well-being or even loss of life, and in the destruction of property. A few facts properly evaluated should restore confidence as to how one may be safe in his environment wherever he is.

Initially, in telegraph service, gaseous atmospheres were considered primarily a problem of the outside plant forces but changes in the type of some of the commonly employed gases and flammable liquids, as well as their broadened use in recent years, have led to the realization that the problem is of serious moment to the inside plant forces, as well as to the employee in his home environment. Due to the fact that problems of an identical nature will arise in the event of a war emergency, these data will be of interest to the employee in Civil Defense and similar work in his home community.

The increase in the dangers involved with explosive atmospheres caused Western Union to study the problem more thoroughly and to develop a simple and accurate method of determining the presence of explosive gases or gaseous vapors in enclosed atmospheres. This method and the detector apparatus will be described later in this article.

Classification of Atmospheres

Following are the four general classifications of dangerous atmospheres into one or more of which an otherwise safe atmosphere may be quickly changed, often without apparent warning:

1. *Explosive or Flammable Atmospheres.* This article describes the dangers involved where explosive atmospheres are encountered and indicates either the control or procedures which make for intelligent and safe action.

2. *Deficiency of Oxygen.* Deficiency of oxygen may occur in the same atmosphere containing explosive constituents, or in an ordinary atmosphere where oxygen content has been reduced or removed. Since deficiency of oxygen is often closely related to the explosive problem and because oxygen deficiency, even where explosive gases are not involved, can be as serious as any of the other three categories, the method of determining whether an atmosphere is deficient in oxygen was included in our investigation and it was found practicable to incorporate it in the apparatus developed for testing explosive atmospheres.

3. *Poisonous or Toxic Atmospheres.* This category will not be covered in this article because the effects, methods of detection, proportions of the gas in the air and other factors are entirely different from the problems involving

explosive gases. Poisonous gases will, therefore, be covered in a separate article at a later date

4. *Concentrations of Materials in the Air* This article does not consider in detail the problems of concentrations of materials in the air, referred to by various designations of which "smog" is one. That problem involves contaminations in the general outside atmospheres of a city or local community and, therefore, must be studied, considered and controlled by municipal or state action. This article, to the contrary, is more concerned with problems involving atmospheres in confined or enclosed spaces where the individual has control, or at least it is hoped that he will have control after an understanding of the gaseous atmospheres is acquired

Explosive Gas or Gaseous Vapor Atmospheres

Explosive atmospheres have been rated first in the foregoing group of contaminated atmospheres because of the increasing dangers both in industry and in the home. Natural gases have been quite generally substituted for manufactured gas which circumstance, together with the more extensive use of flammable liquids such as gasoline, have gradually become so common that there has arisen an apparent lack of the necessary respect which is due to substances with such potential hazards.

For example, manufactured gas, often referred to as illuminating gas, was supplied for many years for illuminating purposes, for cooking and for heating water. Later, the illuminating use disappeared but a start was made in space heating with it. Now, natural gas has largely superseded the manufactured type and the quantity consumed in space heating has greatly expanded. This general change in use would not be of any great moment if it were not for the fact that natural gas does not contain the poisonous or toxic carbon monoxide gas which is an appreciable constituent of manufactured gas, and because of absence of this poisonous constituent, the stench gas normally added to manufactured gas is not in general included in the natural gas. The absence of a poisonous gas, as well as of stench gas in the natural gas, has caused a quite natural tendency to pay little attention to the presence of the natural gas on the assumption that it is not harmful. While it is not toxic, it is explosive and herein lies the danger

In order to provide a background of some of the common gases and inflammable liquids which give off gaseous vapors that can cause serious fires and explosions, Table I supplies general data for the discussions which are included in this article. This table also lists atmospheres that may become deficient in oxygen, as well as some of the more usual sources of the gases and where they are frequently found.

Characteristics of Explosive Atmospheres

The gases or flammable liquids in containers labeled "Explosive Gas," or "Flammable Gas," or "Flammable Liquid," are really not explosive of themselves since 100 percent of the gas or of the gaseous vapor will neither explode nor burn. An explosive gas or gaseous vapor when mixed with air is, however, capable of forming atmospheres that are highly explosive

There are three categories of such gaseous air mixtures:

(a) Nonexplosive. Incapable of exploding or burning. (Mixtures *below the lower limits of explosibility*)

(b) Explosive. (Mixtures *between the lower and upper limits* of explosibility)

(c) Not Explosive but capable of exploding with the addition of air (*Above the upper limits* of explosibility)

Figure 1 shows, percentagewise, for each of a number of common gases and liquids, the amount of gas or gaseous

TABLE I

COMMON GASES FOUND IN ENCLOSED SPACES—EXPLOSIVE, OXYGEN DEFICIENT AND SUFFOCATING—SOURCES, CHARACTERISTIC ODORS, WHERE FOUND

Name of Gas or Gaseous Vapor	Source	Odor	Where Commonly Found
(A) Explosive Gases			
Natural Gas	Gas Mains—Oil Wells—Gas Cylinders—Mines—Etc.	None	Manholes—Basements—Schools—Dwellings—Factories
Gasoline, Benzol (See Note)	Storage Tanks—Airplanes—Automobiles	Characteristic of Gasoline	Garages—Manholes—Storage Tanks—Hangers—Airplanes—Dry Cleaning Establishments—Motor Boats
Propane	Gas Cylinders—Tanks	None	Home Cooking—Water Heating—Manufacturing Operations
Methane	Natural Gas—Some Sewer Gases—Mfd. Gas—Cylinders	None	Schools—Factories—Dwellings—Basements—Manholes
Ethane	Gas Cylinders—Mfd. Gas—Natural Gas	None	Schools—Factories—Dwellings—Manholes—Basements
Butane	Liquefied Petroleum—Gas Cylinders—Mfd. Gas	None (Except Stench Gas in Mfd. Gas)	Manholes—Tunnels—Excavations
Hydrogen	Gas Cylinders—Mfd. Gas—Electrolysis H_2O	None	Battery Rooms—Same as Mfd. Gas
Carbon Monoxide	Mfd. Gas—Flue Gas—Auto Exhaust Gases—Incomplete Combustion	None	Garages—Emergency Engines—Same as Mfd. Gas
Manufactured Gas	Mfd. Fuel Gas—Gas Mains	Added Stench Gas	Homes—Schools—Factories—Basements—Manholes
Acetylene	Gas Cylinders—Generators	Characteristic Odor	
Ammonia	Ammonia Fluid—Refrigeration Systems	Characteristic Odor	Large Cold Storage Plants—Home Cleaning Fluid
Turpentine	Paints—Varnishes—Cleaning Fluids	Characteristic Odor	Homes—Paint and Varnish Factories
(B) Oxygen Deficient and Suffocating Gases			
Carbon Dioxide	Products of Combustion—Sewer Gas	None (Respiratory Stimulant)	Garages—Tunnels—Manholes
Nitrogen	Products of Combustion—Gas Pressure Tanks—Factory Processes	None	Factories—Tunnels—Garages—Manholes
Natural Gas	Gas Mains—Tanks	None	Manholes—Excavations—Dwellings—Basements—Factories—Tunnels
Butane	Liquefied Petroleum Gas—Mfd. Gas—Tanks	None (Except Stench Gas in Mfd. Gas)	Manholes—Tunnels—Excavations
Air	Atmospheres with (a) an excess of Explosive Non-Poisonous Gas, or (b) a Deficiency in Oxygen	None	Everywhere

Note: Gasoline Vapor is an anesthetic. Liquid Gasoline is poisonous.

vapor by volume in a gas-air mixture that determines whether the mixture is below the lower explosive limit, in the explosive range or above the upper explosive limit. It will be noted that in many cases the explosive ranges, shown in black, are quite narrow, while the ranges for those mixtures above the upper limits of explosibility (horizontal shading) are wide. In the cases of hydrogen, acetylene and carbon monoxide this condition is reversed. While there are some sixteen

A certain temperature is required to ignite each gaseous mixture which varies only with the different gases. From Figure 2 it will be seen that the ignition temperatures, shown by Curve A, vary from a low of 495 degrees F for gasoline vapor to a high of 1204 degrees F for carbon monoxide gas-air mixtures.

Curve B of Figure 2 shows the vapor densities of the same gases. Where the vapor density is high, the gaseous vapor mixture will tend to stay down near the

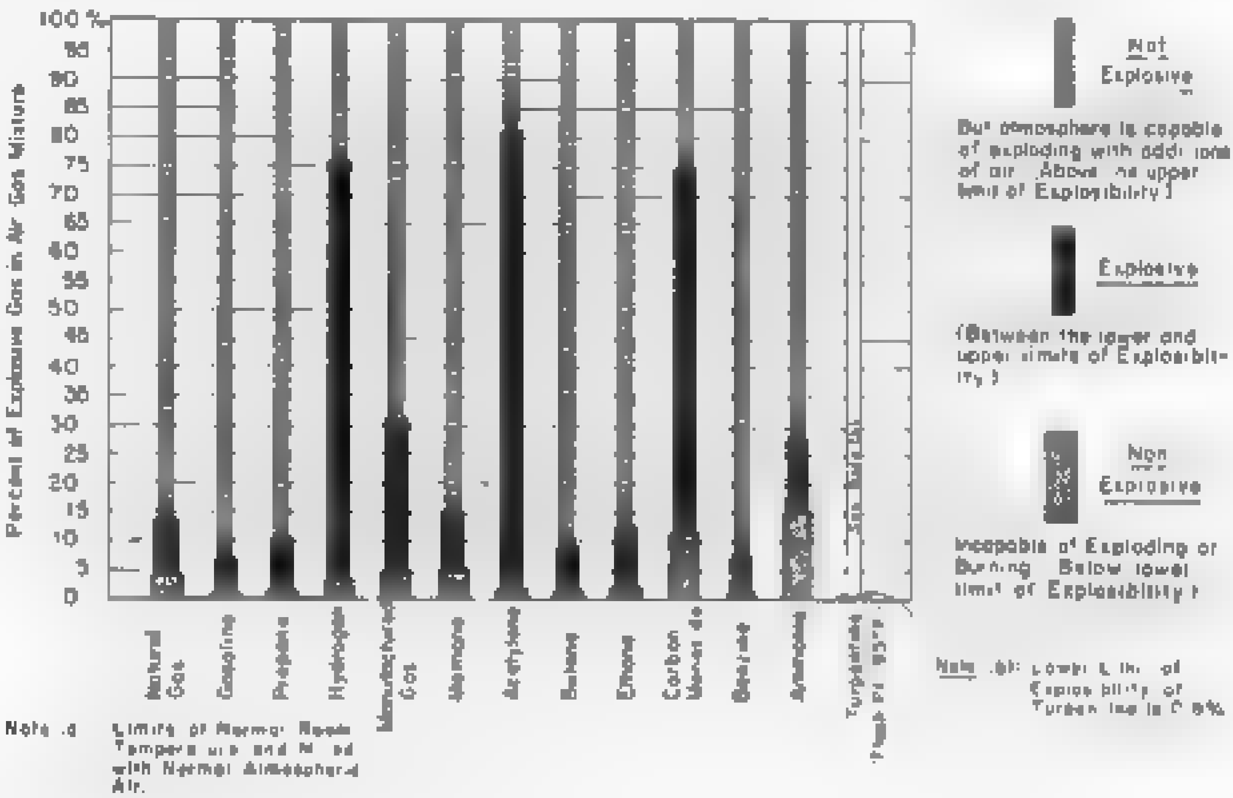


Figure 1 Limits of explosibility of various gases mixed with air

characteristics that are important under certain circumstances, two of them are important here first the ignition temperature and second the vapor density

An explosive mixture first requires a temperature sufficiently high to ignite it. After ignition, however, gaseous mixtures can propagate a flame upward, downward, or horizontally. Since the upward propagation is the most sensitive, it is the one generally considered in most safety work. The statement often made that the temperature of ignition affects the limits of explosibility is not true, since the difference observed is not in the ignition temperature but in the flame propagation.

floor or ground level and diffuse slowly, whereas a low vapor density will cause the mixture to rise and thus tend to diffuse more readily. Here again, gasoline vapor has one of the extreme values of the gases and vapors shown, with a vapor density of 3 to 4, while hydrogen is the lightest, having a vapor density of only 0.069

The upper and lower limits of explosibility shown in Figure 1 are correct for these gases at normal room temperatures when they are mixed with normal atmospheric air. When two or more are mixed together, or when the proportions of any of the constituent gases are changed, the limits may change since Le Chatelier's

law states that the explosive range of a mixture of gases is dependent on the percentage of the constituent gases and on the limits of explosibility of each constituent. This is why it is necessary in using most test instruments to identify the gas to be tested and to have the instrument calibrated for that gas. Western Union's Detector Indicator does not require either identification of the gas under test or calibration in order to determine if any hazard exists.

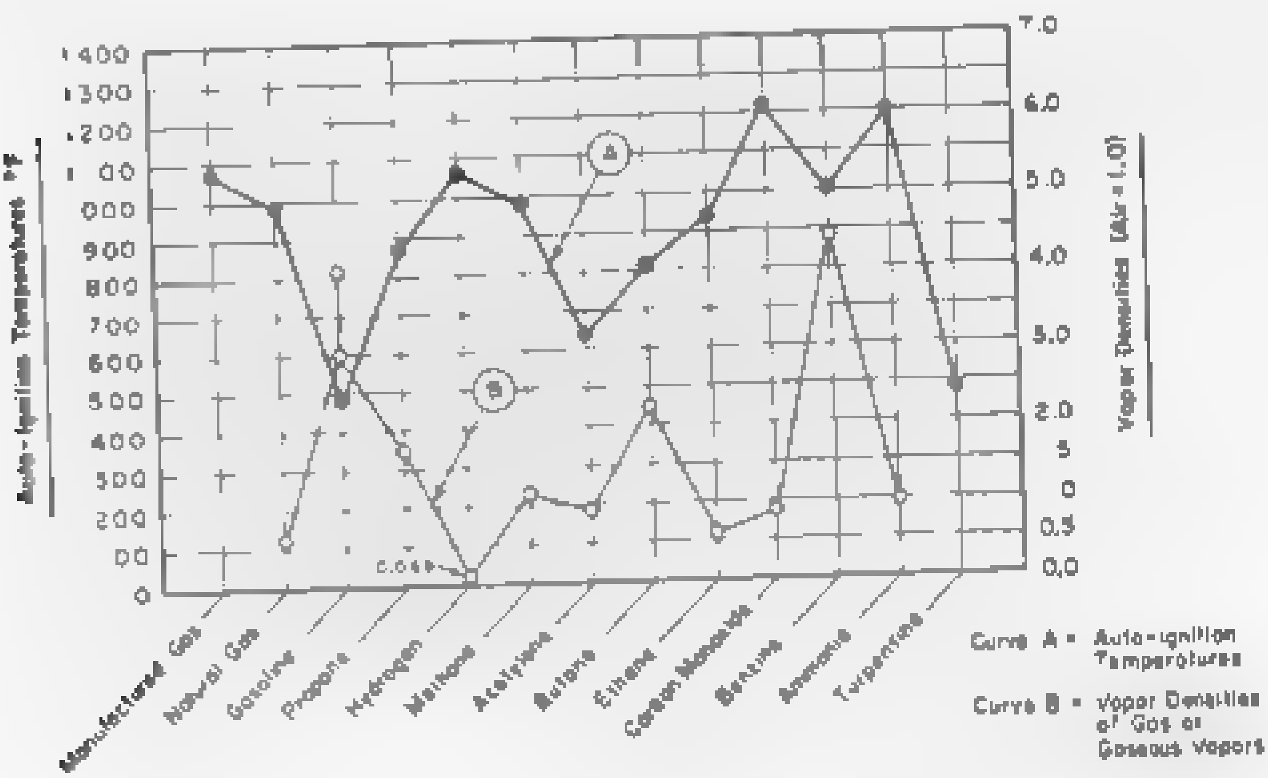


Figure 2 Ignition temperature and vapor density of common gases and gaseous vapors

Natural Gas Mixtures

From Figure 1 it will be noted that natural gas-air mixtures are not explosive in the cross-shaded section of the bar between 0.0 percent and 4.8 percent of the gas in the mixture, the latter value being the lower limit of explosibility. In the solid shaded portion, the mixtures are all highly explosive. In the horizontally shaded portion, the mixtures are not explosive but only because there is insufficient air (oxygen).

It must now be apparent from Figure 1 that since natural gas mixtures in the cross-shaded portion of the bar just below the lower limits of explosibility can change from an inert, odorless, nonpoisonous mixture to a highly explosive atmosphere with the addition of less than 1 percent of the gas, a very serious situation can be encountered, or avoided by a proper understanding of the condition of such an atmosphere.

Table II shows this condition of natural gas in more detail. The maximum gas content in the group covered by Note (a) is 4 percent. Now, the addition of air, even an amount as small as a fraction of 1 percent, will cause this atmosphere to be definitely incapable of either exploding or burning, whereas the exact opposite would be true if 1 percent of the gas were added.

All of the gas mixtures referred to in Note (b) in Table II are instantly explosive and they will explode whenever the temperature of ignition for this gas is applied.

The gas mixtures covered by Note (c) in Table II are all above the upper limit of explosibility and therefore are not explosive, as shown. However, with all these mixtures the addition of air reverses the condition and, in the case of those close to

TABLE II

EXPLOSIVE CHARACTERISTICS OF NATURAL GAS-AIR MIXTURES

MIXTURES IN %

	NATURAL GAS	AIR (21% O_2—79% N_2)	CONDITION OF MIXTURES	
	0.0	100.0	Nonexplosive	
	1.0	99.0	Nonexplosive	
	2.0	98.0	Nonexplosive	See
	3.0	97.0	Nonexplosive	Note
	4.0	96.0	Nonexplosive	(a)
Lower Limit	4.8	95.2	Explosive	
	6.0	94.0	Explosive	
	8.0	92.0	Explosive	
	10.0	90.0	Explosive	See
	12.0	88.0	Explosive	Note
Upper Limit	14.0	86.0	Explosive	(b)
	15.0	85.0	Not explosive	
	20.0	80.0	Not explosive	
	40.0	60.0	Not explosive	
	60.0	40.0	Not explosive	See
	80.0	20.0	Not explosive	Note
	100.0	0.0	Not explosive	(c)

Note (a) All mixtures described as "Nonexplosive" not capable of exploding.

Note (b) All mixtures described as "Explosive" immediately explosive.

Note (c) All mixtures described as "Not explosive" are not explosive but become instantly explosive with the addition of the proper amount of air.

the mixtures included under Note (b), the addition of a small amount of air would cause them to become explosive. The mixtures in the group covered by Note (c) need only a proportionately greater amount of air to make each of them explosive; thus, the opening of a door, a window or manhole cover could cause all these mixtures to become explosive. In the case of explosive mixtures close to those of Note (a), the admission of air in a similar manner would produce the exact opposite effect.

Reference to Figure 2 will show that the vapor density of natural gas is less than that of air so the gas will rise and diffuse when it is introduced into an atmosphere. While the ignition temperature of natural gas is relatively high, being only slightly below 1,000 degrees F, a spark, a match or even a lighted cigarette is all that is needed to set off an explosion of all of the gas-air mixtures which are in the explosive range.

An illustration will serve to show that complacency in the handling of natural gas is dangerous. In the early periods of the use of natural gas, it was used primarily in the vicinity of the oil producing fields. In the Texas oil fields in 1937 a new high school was built at New London, Texas and was heated with natural gas. Ten minutes before the dismissal of classes on March 18, 1937, an explosion completely wrecked the new fireproof building and killed 427 students and teachers. Today, natural gas is no longer used only in localized areas such as near the oil fields but has been piped into considerable sections of the country, hundreds and even thousands of miles from its source.

Natural gas varies in consistency in various parts of the country and, consequently, its explosive limits will also vary slightly from the limits shown in Table II. These variations may cause a small change in the lower limits of explosibility, probably as much as 1 percent, but only about 0.5 percent in the upper explosive limits. For all practical purposes, however, the limits of explosibility of natural gas, as shown in Table II, are substantially correct. The principal constituents of two typical natural gases are as follows:

	(a)	(b)
Methane (CH_4)	87.4	84.7
Ethane (C_2H_6)	6.5	9.4
Propane (C_3H_8)	1.55	3.0
Butane (C_4H_{10})	0.51	1.3
Pentane (C_5H_{12})	0.00	trace
Nitrogen (N_2)	3.20	none
Oxygen (O_2)	0.20	none

In these two natural gas compositions none of the constituent gases have characteristic odors nor do any of them have pungent characteristics. Most gases, however, even if rated as odorless, after having been in a tank or a gas main appear to take on a stagnant or "dead" gas odor which is usually just sufficiently different to be noticeable when it is introduced into the normal atmosphere.

Manufactured Gas Mixtures

Manufactured gas mixtures, as shown in Figure 1, have wider limits of explo-

sibility (5 percent to 36 percent) than natural gas but both have approximately the same lower limits. The higher upper limit of manufactured gas is primarily due to its high hydrogen and carbon monoxide content. All of the constituent gases of manufactured gas, like natural gas, are devoid of characteristic odors but stench gas is added because of the deadly carbon monoxide. The stench gas is easily detectable by the presence of as little as a few parts per million parts of air. Whenever a leak occurs within an inside enclosure, the stench gas constitutes a very effective warning. Where a leak occurs in a street main, however, and the gas flows through the earth, the stench gas is often filtered out by the earth before it gets into a manhole, basement, or other enclosed space. Although manufactured gas has wider limits of explosibility than natural gas, its poisonous gas constituent, carbon monoxide, is the first and greater hazard. This is because carbon monoxide is deadly in minute quantities as low as 0.0005 percent of the gas. On the other hand, to be explosive manufactured gas requires a minimum of 5.0 percent gas. The necessity to detect manufactured gas in minute concentrations due to its poisonous constituent probably accounts for the lesser number of explosions in its use in the past.

Gasoline Vapor Mixtures

Because gasoline is a typical flammable liquid and is so generally employed in industry, in various forms of transportation and in the home, it will be treated in more detail than other liquids in the same general classification. It will be noted from Figure 1 that gasoline vapor mixtures have one of the lowest of the lower limits of explosibility, which is 1.4 percent. Therefore only 1.4 percent of the gasoline vapor mixed with 98.6 percent of air is needed to make an atmosphere highly explosive. Because of its low lower limit and large explosive force, the Germans immediately prior to World War II experimented with gasoline vapors for use as the explosive element in bombs.

The low limit of explosibility of this vapor has been one of the main causes of many accidents. Gasoline tanks when emptied of all gasoline are usually assumed to be safe. To the contrary, this is when they are very dangerous. An understanding of this simple fact could have averted danger on March 7, 1957, when a man at Oakland, N. J., was cutting up old cars with his acetylene torch. A gasoline tank exploded, throwing him 20 feet in the air and the man died in the hospital. At a small town adjacent to Camden, N. J., on April 6, 1957, two 3,000-gallon tanks were completely emptied of gasoline and removed from the ground where they had been buried. The tanks, fortunately in a remote area, exploded during the night. The force of the explosion rocked the entire town, blew out windows at considerable distances, and set fire to adjacent property. The tanks were empty but a source of ignition, plus the small vapor content necessary, was nevertheless present. Had the tanks been full of gasoline they would not have exploded, or if sufficient gasoline had been present so that the vapor content would have been more than 8 percent, the tanks would not have exploded. The admission of air, instead of making the tanks nonexplosive, to the contrary made them highly explosive.

A similar action takes place in various gasoline engines, such as in automobiles, trucks, power mowers, auxiliary power plants, and so forth. When the gasoline vapor is present between the limits of 1.4 percent to 7.6 percent, the motor will function perfectly, but it will stall when the gasoline vapor proportion exceeds 7.6 percent, or whenever it is less than 1.4 percent. Whenever the mixture exceeds 7.6 percent of gaseous vapor, the motor will not start, or if started will not continue to function. By holding the accelerator of an engine having an automatic type choke completely down, air will be admitted into the carburetor in excess, thus causing the mixture to be lowered from above the upper limit of explosibility to within the explosive range. The motor will then readily start and continue to function.

Thus, gasoline vapor mixed with air in one case produced an explosive mixture which resulted in disaster, while in another case a similar explosive mixture

produced in the proper enclosure is safely translated into useful work.

Another important factor which must be taken into consideration with vapor mixtures, and in particular gasoline, is their auto-ignition temperatures. Gasoline has one of the lowest ignition temperatures of any of the gases or gaseous vapors listed, namely, 495 degrees F. This temperature approximates soft soldering temperatures and means that if a gasoline tank were emptied of all gasoline it would not be safe to solder it. Even if the soldering were being done on the outside of the tank, the moment the tank wall reached a temperature of 500 degrees F or more, an explosive gaseous vapor mixture within would be ignited and explode with tremendous force.

While the burning of gasoline may present a serious threat, the explosive characteristic of its vapor-air mixture presents a far more serious hazard from the standpoint of loss of life and property. One gallon of gasoline completely vaporized is equivalent to the explosive force of 87 pounds of dynamite, and 87 pounds of dynamite translated into sticks is equivalent to about 350 sticks.

The tremendous explosive force of gasoline resulted in many serious losses in the last war. In the early days of the war the aircraft carrier Lexington was torpedoed by the Japanese but not fatally damaged. The watertight compartments had been closed after the Japanese attack, and the Lexington was proceeding without list back to its base in Australia under its own power at 25 knots, when gasoline vapor explosions rocked the ship. A series of explosions released more gasoline and other explosions continued until the communication, control and electric power systems were wrecked beyond repair. Out of control and with explosion after explosion accompanied by fires, the Lexington was completely wrecked, ordered abandoned, and later sunk by torpedoes from American destroyers. Thus the Lexington, paradoxically, was neither mortally wounded nor sunk by Japanese torpedoes but was destroyed by gasoline vapor explosions.

In connection with this large explosive force of gasoline vapors, it is necessary to understand the difference between fires and explosions. A *fire* can be fought at any time and overcome; delay in starting the action increases the damage, but a *fire can be stopped. Explosions,* to the contrary, must be either *prevented or controlled,* they *cannot be stopped after they have been initiated.*

Consideration must be given to both fire and explosion in dealing with flammable liquids, otherwise one may find that the fire has been conquered only to lose all because the explosive element of the vapors and their underlying causes had not been controlled. There are several characteristics which must be understood in order to deal intelligently with the problem:

(1) The narrower the explosive range of the gaseous vapor of a flammable liquid, the greater the force of an explosion. Reference to Figure 1 shows that gasoline has a very narrow explosive range.

(2) A narrow explosive range combined with a low lower limit of explosibility increases the relative hazard. Reference to Figure 1 shows the lower limit of explosibility of gasoline to be one of the lowest.

(3) A low auto-ignition temperature increases the probability and relative hazard of an explosion. Gasoline has an extremely low auto-ignition temperature, as shown by Figure 2.

(4) A high vapor density retains the explosive vapors at the lower or floor levels of enclosed spaces. Gasoline vapors have one of the highest vapor densities of those shown on Figure 2.

The reduction of the oxygen content of a gaseous vapor air mixture can be employed to extinguish a fire; that is, reducing the oxygen content to about 16 percent will, in general, cause a flame to be extinguished but, unfortunately, does not always guarantee the avoidance of an explosion. Therefore, blanketing burning gasoline in an enclosed space with foam or steam may extinguish the flames by reduction of the oxygen content of the air but successive explosions often continue since gasoline vapors may explode when the oxygen content is as low as 11.5

percent. One method of both extinguishing fires and avoiding explosions is to add an inert gas to the atmosphere in the tank, compartment or enclosed space. The kind of inert gas employed would determine the degree of the effectiveness of this method which would, however, be effective even if the temperature of ignition were present.

The reduction of the oxygen content has the effect of narrowing the normal explosive range of a gaseous vapor. Therefore, since the process of fire extinguishment reduces the oxygen content, it is evident that such a procedure would narrow the explosive range to a greater extent and, hence, would add to the explosive force of the gaseous vapor mixture. This sequence accounts for the tremendous force of many gasoline vapor explosions, and the large damage often credited to other sources.

Another characteristic of a vapor mixture is the effect of temperature on a flammable liquid. With any increase in temperature above normal, the limits of explosibility will tend to widen, reducing the lower limits and increasing the upper limits. With gasoline, for example, its lower limit obviously would not require very much reduction for it to approach to zero. With such a change, as reference to Figure 1 will show, many gasoline vapor mixtures which heretofore were nonexplosive will be made explosive. Similarly, with a normal upper explosive limit of 7.6 percent increased to a higher value, many other mixtures that otherwise would have been nonexplosive would be brought into the widened explosive range.

Thus, under certain conditions, the temperature increase will counterbalance the increase in explosive force mentioned above but the over-all hazard is not reduced and may even be increased due to the widened limits of explosibility.

The fact that gasoline is potentially extremely dangerous should always be kept in mind in dealing with it, and the fact that carelessness is not always penalized by fires or explosions, due purely to good fortune, should not lull one into a false sense of security.

Propane Gas Mixtures

Propane gas is being used more generally in both industry and in the home. It is very desirable and burns with a hot, clean, smokeless flame. It is odorless and is free of toxic elements. However, this gas is dangerous because of the latter characteristics which, as with natural gas, tend to give the impression of safety whereas there is actually great danger because of its highly explosive characteristics. Also, as will be noted from Figure 1, propane has a very low limit of explosibility (2.4 percent) which is similar to gasoline, and also like gasoline has a narrow explosive range having an upper limit of only 9.5 percent. There is another characteristic of propane which makes its vapor mixtures particularly dangerous, and that is its vapor density, which is 1.59. Since the vapor is thus heavier than air, the gas will stay near the lower level of rooms, manholes, basements and other enclosures. Ventilation, therefore, must be applied to the lower portions of the enclosure.

Hydrogen Gas Mixtures

Hydrogen is used in laboratories, is readily generated in the charging of storage batteries and in electrolysis processes, and is employed in certain industrial applications. Hydrogen, it will be noted from Figure 1, has very wide limits of explosibility at normal atmospheric temperatures. Because of the relatively low value of its lower limits and because of its wide explosive range, hydrogen is considered very dangerous. It is not toxic, is without a characteristic odor but, due to its very low vapor density, the gas rises and tends to diffuse easily throughout enclosed spaces. Thus, hydrogen can be injected into an atmosphere and all mixtures of that atmosphere containing from 4 percent to 75 percent of the gas will be explosive. Great care must, therefore, be exercised where storage batteries are being charged in enclosed spaces, and where hydrogen is used in welding or other manufacturing processes. Ventilation for hydrogen, un-

like for propane, must be applied to the upper portions or levels of an enclosure.

Turpentine Vapor Mixtures

Turpentine is widely used in enclosed spaces and should be handled more carefully than is the usual practice. Its vapors are explosive at normal temperatures with a lower limit of explosibility lower than that of most industrial vapors, namely, 0.8 percent. Thus, with 99.2 percent of air, an explosive mixture is present at 70 degrees F. Raising the temperature to 212 degrees F reduces the lower limit to only 0.69 percent. The auto-ignition temperature of turpentine, like that of gasoline, is very low, being only 488 degrees F.

Oxygen Deficient Atmospheres

Oxygen deficiency can occur in an atmosphere containing explosive or other foreign gases or it can be an atmosphere merely deficient in oxygen. In either case it is dangerous. As explained under the explosive characteristics of gases, the addition of air to an atmosphere deficient in oxygen can make explosive an atmosphere containing explosive gases above the upper limit.

A most serious situation, however, can result from oxygen deficiency bearing no relation to explosive gas atmospheres, which also may be the result of either complacency or ignorance. It is commonly thought, for example, that a deficiency of oxygen in an otherwise normal atmosphere will result in difficult breathing and suffocation, and that it may ultimately lead to death. This is correct. Suffocation is usually slow and its progress can be reversed if discovered in time. What is not generally known, however, is that where the oxygen content is below a critical percentage that atmosphere will be just as dangerous as if it contained the most poisonous or explosive of gases, since the effects on the individual cannot be reversed. In usual cases of suffocation some oxygen remains in the lungs, whereas breathing air without oxygen rapidly displaces all oxygen in the lungs, causing almost instant death.

With the normal oxygen content in air of 21 percent lowered to a content of 12 percent to 16 percent, the result will be drowsiness, headaches and gradual suffocation, but when the oxygen content is reduced to about 6 percent the atmosphere will produce quick death within a shorter period than suffocation but still with some time factor being involved. This is serious enough, but when the oxygen content approaches zero no appreciable time period is involved to produce death. It has been established that workmen in manholes have been killed practically instantaneously in such an atmosphere. Tests afterwards showed that canaries and hamsters lowered into the same atmosphere died instantly, although there was not even a trace of a poisonous or foreign gas, only air with its oxygen content lowered to 3.2 percent four feet from the bottom and to 0.0 percent at the bottom of the manhole. Thus, death from a serious deficiency of oxygen resulted as quickly, or even more quickly, than would have been the case had the atmosphere contained hydrocyanic acid (HCN) which is considered one of the most toxic or poisonous of all substances.

Explosive Gas Detector and Oxygen Deficiency Indicator

The increase in the dangers involved with explosive and oxygen deficient atmospheres caused Western Union to give special consideration to safeguarding the lives of its employees and its property.

The problem of explosive gases as affecting Western Union is somewhat different than that confronting many companies which are frequently concerned with only one gas or with a single flammable liquid vapor. Western Union, to the contrary, is confronted with a number of gases including natural gas, manufactured gas, enriched gas, gasoline and benzene vapors, propane, methane, acetylene, oxygen, hydrogen, and so forth. Often the gases encountered are in different proportions and, frequently, are mixtures of two or more

In addition to explosive atmospheres, the problem of oxygen deficiency had to be considered.

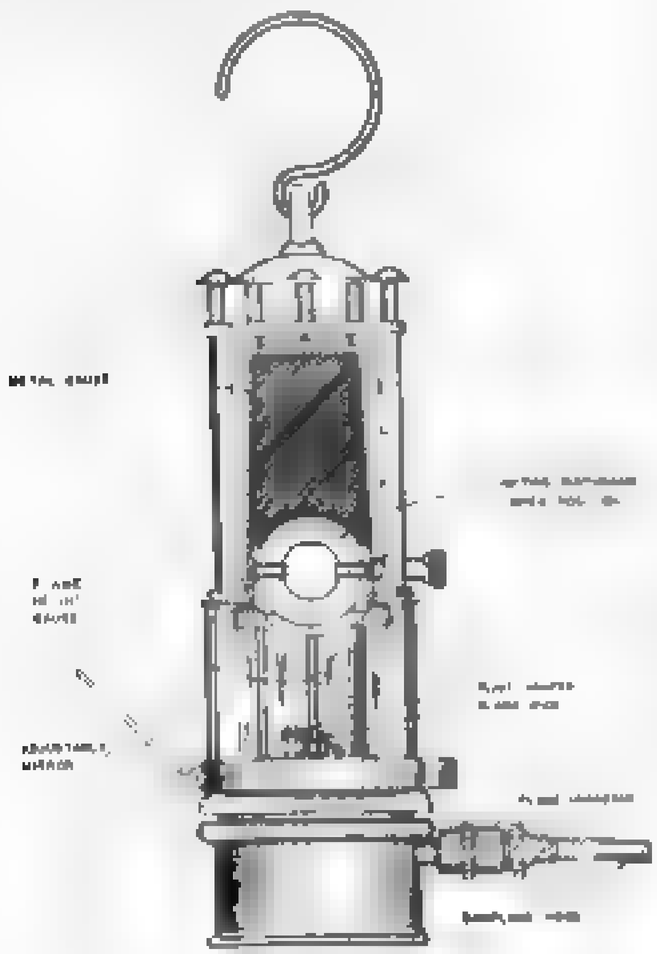


Figure 3. Explosive gas detector and oxygen deficiency indicator

Western Union, therefore, developed a detector to cope with this rather broad range of conditions and gave it the name of "Explosive Gas Detector and Oxygen Deficiency Indicator." This Detector Indicator shown by Figure 3 is accurate, simple to operate, and consists of a flame in a controlled enclosed space into which the atmosphere to be tested is introduced by aspiration. A somewhat similar method was available but Western Union had not previously used it because the equipment was seriously inaccurate and unsafe to use, due to the fact that the amount of air introduced at the top to support the flame was so far in excess of that required by the normal flame as to seriously dilute the atmosphere being tested.

After testing and discarding various commercial detectors, including the flame type, it was found that by introducing a limiting diaphragm, so designed with perforations as to permit the entrance of only sufficient oxygen to sustain a normal test flame, all surplus air could be excluded. The perforated diaphragm was so designed that even the controlled inward flow of air to the normal test flame due to convection was, for the duration of the tests, completely and automatically cut off by the test atmosphere when introduced into the test chamber. The latter action thus makes the flame a responsive test flame thereafter entirely dependent upon, and respondent only to, the atmosphere under test.

In using the Detector-Indicator, observations of the behavior of the flame as the atmosphere under test is aspirated into the lamp indicate the presence or absence of explosive constituents, whether the atmosphere is below the lower limit of explosibility, within the explosive range or above the upper limit of explosibility and, if no explosive elements are present, any lack of oxygen.

If the flame *rises slightly* some form of explosive gas or gaseous vapor is present but its gas-air mixture is below the lower explosive limit. If it *rises very high* or is *extinguished by a small explosion* the atmosphere is within the explosive range. If the flame *first rises and then falls* the atmosphere contains explosive gas but is above the upper limit of explosibility.

If the flame *immediately decreases* or *changes color* a lack of oxygen is indicated; if it is *immediately extinguished*, without violence, the oxygen deficiency is serious. Obviously, if explosive gas is present any lack of oxygen will be masked by the reaction of the explosive gas but the steps specified to clear the atmosphere of the gas will also remedy the oxygen deficiency.

This apparatus is not intended to be taken into the atmosphere being tested but instead is designed to have the sampling hose introduced into the atmosphere which is then aspirated into the detector. Even though the apparatus is safe for use in many atmospheres, there are some which contain certain gases that may be ignited even though the Detector is equipped with two safety devices to pre-

vent such a hazard. The Detector, excepting the sampling hose, therefore should always be kept outside of any suspicious atmospheres

The Western Union Detector-Indicator is the only apparatus that not only tests for all kinds of explosive gas and oxygen deficient atmospheres but, in addition, indicates the condition of an atmosphere quantitatively to a sufficient degree to show: first, whether any explosive gases are present (including gasoline vapor in which the tests are made without the use of inhibiter-filters); second, whether the atmosphere if explosive gases are present, is below the lower limit of explosibility third, whether the atmosphere containing explosive gases is above the upper limit of explosibility (tests are made without the use of any air dilution system); fourth, whether the atmosphere is deficient in oxygen and no explosive gas is present. Although the apparatus does test for oxygen deficiency in an atmosphere containing explosive gases, such dual test is not utilized because the indication of the explosive gas hazard is a sufficient warning of danger Inasmuch as all of the foregoing tests are made without calibration of the apparatus for different explosive gases or for the different proportions of the gas mixtures, the utility and simplicity of operation for the rather diverse needs confronting Western Union is apparent.

Better Safe Than Sorry

The foregoing general discussion of the characteristics of explosive mixtures and the detailed explanation of certain of the gases, gaseous vapor mixtures and flammable liquids, should serve as a guide to their safe handling as well as a general guide in the handling of other similar gases or gaseous vapor mixtures.

In the fighting of fires, and in the prevention or control of the causes underlying explosions, a *modus operandi* must be developed which must include a detailed knowledge of each gas, flammable liquid or vapor, and its characteristics This article is not intended to present or to take the place of such a *modus operandi*, but it is rather intended to assist in the avoidance of various conditions which may be, and usually are, the cause of initiating or precipitating either fires, explosions, or both. Nevertheless, sufficient data are given herein to show one how to act intelligently if confronted with the presence of either an explosive gas mixture, a gaseous vapor mixture, or a deficiency in oxygen, and how to proceed in any particularly hazardous situation, without precipitating the very accident, fire or explosion he was hoping to prevent.

If in an atmosphere thought to contain explosive gases or gaseous vapors, act cautiously, promptly and intelligently Get out of the atmosphere immediately, but even then get out intelligently Do not flip a switch either on or off, do not light a cigar, cigarette or pipe If one is lighted do not puff it as this increases the ignition temperature of the lighted portion If a flashlight is on when the atmosphere is entered, let it remain on but do not switch it on or off within or even near the contaminated atmosphere Let an expert advise on how to turn off electric lights, pilot lights, or other sources of heat in order to eliminate sources of ignition In like manner, do not open doors, windows or manhole covers where explosive gases are present unless you are sure you *know* that what you are doing is the intelligent course to follow under the prevailing circumstances.

Mr. Mompie's biography appeared in the October 1955 issue of TECHNICAL REVIEW.

G. B. WOODMAN, General Maintenance Supervisor, Maintenance and Operations

Improved Vacuum Tube Reliability Through Maintenance

Like most electronic equipment components, commercial vacuum tubes for telecommunications service are subject to well-defined quality control procedures during manufacture. Additional rigorous checking such as microscopic inspection of workmanship above and below mica spacers, radiographic examination of inside plate structures and vibration testing would be difficult to justify, but a combination of short term aging and standard electrical tests has been found practicable and of value.

A CONSIDERABLE library is available on the subject of vacuum tubes. Theory application, operating characteristics, testing and many other details have been covered thoroughly for either the beginner or the advanced engineer. Unending research has been applied to the development of desirable functions and new tube types for specific purposes. Extensive reports are on record for those who are interested in this phase of the work.

It is somewhat more difficult to locate material dealing with maintenance practices and actual field operating results with vacuum tubes. In the maintenance of Western Union carrier and radio relay systems considerable experience has been accumulated which may be of interest to those who are less concerned with design but are striving to get the maximum return from tubes in service.

In general, the type of tube to be used and the operating conditions have been established in the design of the equipment and therefore there is little that can be done along these lines by the man working to improve service reliability. However, this need not lead to a defeatist attitude that nothing can be accomplished in obtaining fewer outages because of tube failures. Actually, many interruptions which might be caused by tube failures can be eliminated and it is possible by adopting a proper tube processing program to obtain improved circuit performance.

Tube Aging

In a previous article[1] the practice of aging tubes at terminal stations of the Western Union radio relay system was briefly outlined. A more detailed description of this routine is appropriate here.

All tubes used in the microwave system, except Klystrons which are subjected to special treatment, are first tested on a commercial type tube checker before being admitted to the aging test. Tubes which fail to pass the initial check because of defects such as low mutual conductance (G_m), shorts or gas are rejected at once. Those which are satisfactory are then placed in Tube Test Panel 5679 or in a spare radio unit where they are subjected to normal filament, bias and plate voltages for one or two weeks depending on the type of tube. At the end of this period each tube is rechecked on the tube tester and any which fail to meet specifications are rejected. Those passing the post-aging test are identified with their G_m and date of test and become available for spares throughout the system.

Tubes which are sent to other stations are rechecked on receipt to establish a G_m value on the local test set. In addition a second figure is noted which is 80 percent of the new G_m and represents the level of G_m at which the tube is to be removed from service. An exception is made in the case of the 6AC7 where the transconductance may rise as the tube nears the end of its useful life. A filament activity test

is made to determine the need for discarding this type and a decrease of more than 10 percent in G_m indicates that the tube should be rejected.

The above figures have been established as a guide only and no hard and fast rule is intended. Certain types which have a relatively long life with gradual deterioration can safely be permitted to remain in service after the periodic check indicates that they are approaching the discard value. Others must be replaced at once because experience has shown that the transconductance will be dangerously low by the next scheduled check.

Table I shows the form used in recording data on tubes being processed. Two columns of mutual conductance are provided for the twin triodes. The "IN" column is for recording the G_m at the start of the aging test while the "OUT" column is to show the G_m upon completion of the test. A decrease of more than 20 percent between "OUT" and "IN" is cause for discarding the tubes. On the reverse side of the form is space to record the reasons for rejection; i.e., low G_m, gas, shorted elements, burned out filaments, and so forth.

Data obtained from these forms have been analyzed and Table II summarizes by tube types the results obtained over a period of one year with several hundreds of tubes aged. It is apparent that the percentage of discarded tubes varies considerably with the type, ranging from 9.44 percent for the 6AS7 to 0.63 percent

TABLE I

RADIO RELAY SYSTEM — TUBE AGING REPORT

TUBES PASSED

	MUTUAL #1 CONDUCTANCE		MUTUAL #2 CONDUCTANCE			MUTUAL #1 CONDUCTANCE		MUTUAL #2 CONDUCTANCE	
TYPE	IN	OUT	IN	OUT	TYPE	IN	OUT	IN	OUT
6SN7	2550	2400	2550	2500	6SL7				
6SN7	2600	2550	2500	2500	6SL7				
6SN7	2300	2200	2200	2000	6SL7				
6SN7					6SL7				
6SN7					6SL7				
6AS7	3900	3800	3800	3800	6SL7				
6AS7	3450	3900	3400	3900	6SL7				
6AS7	3600	3650	3600	3700	6SL7				
6AS7	3800	3800	3900	3800	6SL7				
6AS7					6SL7				
6AS7					6AS7				
6AS7					6AS7				

	MUTUAL CONDUCTANCE			MUTUAL CONDUCTANCE			MUTUAL CONDUCTANCE			TEST READING	
TYPE	IN	OUT	TYPE	IN	OUT	TYPE	IN	OUT	TYPE	IN	OUT
6SH7	4000	3800	6AC7	5500	5500	6V6	4350	4200	6SH7	4200	3850
6SH7	4300	4000	6AC7	5500	5000	6V6	4600	4400	6SH7	3800	3600
6SH7	3900	3500	6AC7	5500	6000	6AC7	5750	6250	6SH7	3900	4000
6SH7	4300	4500	6AC7	5250	4750	6AC7	5000	5250	6SH7	4000	4000
6SH7	4000	3700	6AC7	6500	5500	6AC7	3500	5750	6SH7	4000	3900
6SH7	4000	4000	6AC7	6000	5250	6AC7	6000	5750	6SH7	4000	3900
6SH7	4200	4100	6AC7			[redacted]			6SH7	4400	4150
6SH7	4000	4000									

9 5R4GY tubes passed

0 6H6 tubes passed

for the 5R4GY. This is not too surprising considering the internal construction of the two types. Similar data assembled over another equal period of time indicate a notable similarity in total percentages discarded for each type as well as in each category of failure.

TABLE II

Analysis of Aging Results

Tube Type	Total Aged	Passed	Rejected	Percent Rejected
5R4GY	166	165	1	0.63
6AC7	320	293	27	8.44
6AS7	212	192	20	9.44
6H6	85	83	2	2.36
6SH7	457	436	21	4.59
6SL7	267	258	9	3.37
6SN7	129	127	2	1.55
6V6	110	109	1	0.92

Reasons for Rejection — Percent

Tube Type	Low Gm	Short Grid/K	Short P/Gs	Misc.	Unbalance I_p	Open Filmt.
5R4GY						100.
6AC7	63.	11.			26.	
6AS7	25.	35.			40.	
6H6				100.		
6SH7	33.3	14.3	28.6	9.5		14.3
6SL7	100.					
6SN7	50.	50.				
6V6	100.					

It immediately becomes apparent that one goal of a good maintenance program has been achieved. A number of tubes have been culled which surely would have caused trouble had they been placed in service. This is particularly important in the microwave system for two major reasons. In the first place, the concentration of trunk traffic enhances the need for trouble-free service. Secondly, a majority of these tubes would have been used in isolated, unattended relay stations where a failure generally means a long outage and very possibly calling out a maintainer. Maintainers are on regular duty 40 hours per week at relay stations or 23.8 percent of the time. It seems reasonable to suppose that had the 83 tubes rejected (see Table II) as the result of aging been placed in service, only 23.8 percent would have failed during working hours while 76.2 percent or 63 tubes would have failed during nonworking hours. Disregarding entirely the "down time" of the system as a factor, it is easily seen that a considerable direct saving has been achieved in the elimination of maintenance call-outs.

The case for aging tubes before they are used in the telegraph carrier system is not as clear-cut. Sufficient factual data are not available upon which to form definite conclusions although indications are that aging cannot be justified in general. Currently available information is that less than 1.5 percent of any of the carrier tubes fail in the first two weeks of operation. The cost of an aging program which would reduce this figure must be balanced against the economies of this almost insignificant rate of failure. Should it be decided to process the thousands of tubes before they are sent from the warehouse, the labor cost would be considerable. On the other hand, if a program is set up for field checking, the cost of a large number of test panels might be prohibitive when compared with the results obtained.

Another factor in any aging program for carrier tubes is the value from an operating point of view. The need for processed tubes in carrier service is relatively less than for the microwave system. At carrier installations attendants are generally on duty who can replace failed tubes without delay. Frequently the failure of a tube would interrupt only one channel rather than the hundreds in the radio relay system. Full consideration of these factors might indicate that the aging of selected types, such as those used in the modulating and carrier supply groups, would be sufficient.

Tube Testing

When an electronic system is placed in service it may be assumed that there will be relatively few interruptions during the first few months because of tube failures if aged tubes have been used. However, due to the difference in "normal" life between tubes of the same type and also different types, it will not be long before failures become fortuitous in character.

This can lead to daily interruptions if there is a large number of tubes in the intelligence path. It is imperative that such disruption of traffic be avoided if possible.

Periodic tube checks are of material assistance in this respect; in fact they can be considered a "must" in any program designed to reduce outages. It is important that the checks be scheduled to achieve an optimum balance between an increasing number of failures resulting from infrequent tests and the mechanical and man-made troubles which increase when tests are made too frequently.

In the Western Union microwave system tube checks are made, in general, twice yearly. In certain specific cases it has proved necessary to reduce this interval. Company policy in carrier work is to check tubes which carry multiple channels at six to nine month intervals in general. This includes carrier supply, modulator and line amplifier groups. Tubes in transceivers which carry only single teleprinter channels are not given periodic checks. Deterioration of signal or other indications of imminent failure can be observed and corrections made. A fortuitous failure at this point is not serious because an attendant who can quickly restore service by replacing a failed tube is generally available.

Block Replacement

If tubes could be obtained which would have a predictable and reasonably uniform life expectancy, the need for periodic tube checking would be eliminated. A program for changing all tubes of a particular type in the same panels would be feasible if one could be sure that these tubes had attained 85 to 90 percent of their useful life. Although the manufacturers have accomplished a great deal in lengthening the life of vacuum tubes and have produced tubes much more capable of withstanding shock or vibration, there still seems to be a great discrepancy in life expectancy. The advantages of being able to set up a routine where all tubes of one type in a specific use would be changed at the end of 10, 15, 25 or any other established number of months should be apparent.

Conclusions

Procedures as described above are helpful but are by no means the only practices which will be productive of results. Particular requirements may need various treatments and there are a number of "fringe" conditions which may prove troublesome under certain circumstances. These may require specialized checks. Experience gained over many years indicates, however, that a properly conceived and planned maintenance program for vacuum tubes can be of real benefit in reducing circuit troubles.

Reference

1. MAINTENANCE OF A RADIO RELAY SYSTEM, G. B. WOODMAN, *Western Union Technical Review*, Vol. 5, No. 4, Oct. 1951.

G. B. Woodman graduated from the University of New Hampshire in 1925 with a B.S. degree in Electrical Engineering and immediately joined Western Union. Following a training period at Red Bank, N. J., he was assigned to the former Eastern Division of the Plant Department. Here his work involved the inductive and physical coordination of electric power and Western Union lines. With the advent of the company into the use of carrier, he was associated with field developments in both equipment and lines. Mitigation of extraneous interference and transmission problems of various types were also handled. In 1947 he became a Plant Supervisor on the staff of the Director of Maintenance. His present position is General Maintenance Supervisor on the staff of the Assistant Vice President—Maintenance and Operations. Present duties embrace maintenance supervision of radio relay, carrier, telecar radio, and Marine News reporting by radio.